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JOHN W. FINCH, DIRECTOR

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SAND AND GRAVEL EXCAVATION;

PART 3: HYDRAULIC DREDGE, CLAMSHELL DREDGE, LADDER DREDGE, AND DIPPER DREDGE

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SAND AND GRAVEL EXCAVATION - PART 3:[1] HYDRAULIC DREDGE, CLAMSHELL DREDGE, LADDER DREDGE, AND DIPPER DREDGE

By J. R. Thoenen[2]

INTRODUCTION

This circular is part 3 of the third paper (entitled "Excavation") of a series summarizing the technical problems involved in the production and preparation of sand and gravel. Part 1 discussed the use of power shovels, draglines, and excavator cranes. Part 2 discussed the use of power scrapers, slackline cableway excavators, and hydraulic monitors. This circular discusses the use of the hydraulic, clamshell, ladder, and dipper dredge. Part 4 to follow will discuss the use of haulage equipment, and subsequent parts will discuss the application of both excavating and haulage equipment to various types of deposits.

HYDRAULIC DREDGE

Judged by the number of installations and the tonnage produced, as recorded in part 1 of this circular, the hydraulic or pump dredge is the most popular type of underwater sand and gravel excavator.

Considered as a complete unit, the hydraulic dredge is essentially individualistic in design and reflects a coordination of the requirements of local conditions, operators' desires, and manufacturers' experience. It has no standardization of design. Each dredge is built locally to suit local conditions. Therefore for the purpose of this circular the study of hydraulic dredges must be confined to discussion of the fundamentals governing their construction and operation.

In its simplest form the hydraulic dredge consists of a centrifugal pump and its driving mechanism, mounted on a wooden or steel hull floating on a natural or artificial body of water. (See figs. 7 and 8.) In this form the operation of the dredge may be limited to the excavation of gravel and its delivery to scows moored alongside. As such, it performs the function of an excavator only.

Without any material change in design, this same type of dredge may perform the function of transportation as well as excavation. The only alteration necessary is the extension of the pump-discharge line to the treatment plant on shore, thus eliminating conveyance by barges. Obviously the distance from dredge to plant will govern the scope of work devolving upon the pump.

Where the distance from dredge to plant is too great or presents sufficient difficulties to create a doubt as to the economic advantage of combining excavation and transportation duties in the pump, two alternatives are available to the operator. He can either design his dredge as an excavator only, or he can use a larger hull and install thereon machinery for wholly or partially treating the dredged product. Either alternative leaves the trans-

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portation function to a separate unit consisting usually of towboats and barges. The dredge in the former case reverts to the simplest design and performs the single function of excavation. In the latter case the dredge again performs two functions - excavation and treatment. In the simpler forms of this design the machinery added washes the dredged material and separates the sand from the gravel, discharging both to the transporting unit. The final sizing and preparation for market are done at the shore plant. In the more elaborate development the entire treatment plant is installed on the dredge, and finished products only are shipped from it to distribution or storage yards ashore.

Obviously there is a wide range in the design and size of dredges of this type. An artificially constructed wet pit in which the deposit consists largely of sand will require a very different dredge from one required in a swiftly running river in which the gravel is coarse. The distance from distribution or storage sites and the rate of production will also affect dredge design. If the dredge is located at a distance from its base it may be necessary to provide living quarters on it for the crew. If production demands are great enough it may be necessary to provide quarters sufficiently large for 2 or even 3 crews to enable continuous operation. Irrespective of whether 1 or 3 shifts are worked the volume of production required will affect the size and therefore the design of the dredge.

The hydraulic dredge thus may perform simply the function of excavation, may combine excavation with transportation, or may combine excavation with either partial or complete treatment. These requirements include the great bulk of hydraulic-dredge installations, and the order in which they are discussed probably represents their relative importance in present use.

There have been further elaborations in design, however, and while these installations are comparatively small in number they account for a considerable tonnage and meet successfully the peculiar requirements of their localities.

In this type of design the pump is installed on a self-propelled lake- or ocean-going vessel. This dredge proceeds under its own power to the excavation site, pumps its hold full of gravel, and returns to the shore plant, thus combining excavation and transportation duties. This design, like that on the larger river or wet-pit dredge, has also been carried further. Machinery has been installed for partial or complete preparation of the dredged product on board. Thus the modern type of dredge may combine all three functions of excavation, transportation, and treatment.

It is obvious that hydraulic-dredge design, construction, and operating characteristics cannot be standardized in any but the simplest fundamentals. Consequently hydraulic dredges cannot be constructed, assembled, and shipped as a factory unit as can shovels, draglines, cranes, and scrapers. The dredge hull may be built at the factory, but except in extremely small sizes it must be assembled and equipped at the site at which it is to be used or at a site from which it can be floated to the excavation point.

As an excavating unit the hydraulic dredge consists of a centrifugal pump with its driving mechanism mounted on a floating vessel of more or less elaborate design.

It requires a natural or artificial body of water from which to operate. It removes gravel from below the surface of the water and can excavate dry banks only by undermining and caving them into the water.

The pump itself does not dig gravel. The force which actually brings the gravel to the pump is the transporting power of water put in motion by the pressure of the atmosphere on the water surface. The function of the pump is to destroy the equilibrium of atmospheric pressure by creating a partial vacuum inside its suction pipe. Once the end of the suction is submerged and the pressure equilibrium destroyed, atmospheric pressure on the surface forces water up the pipe to the pump. The power of the moving water to carry gravel with it depends upon its velocity which depends upon the design and efficiency of the pump.

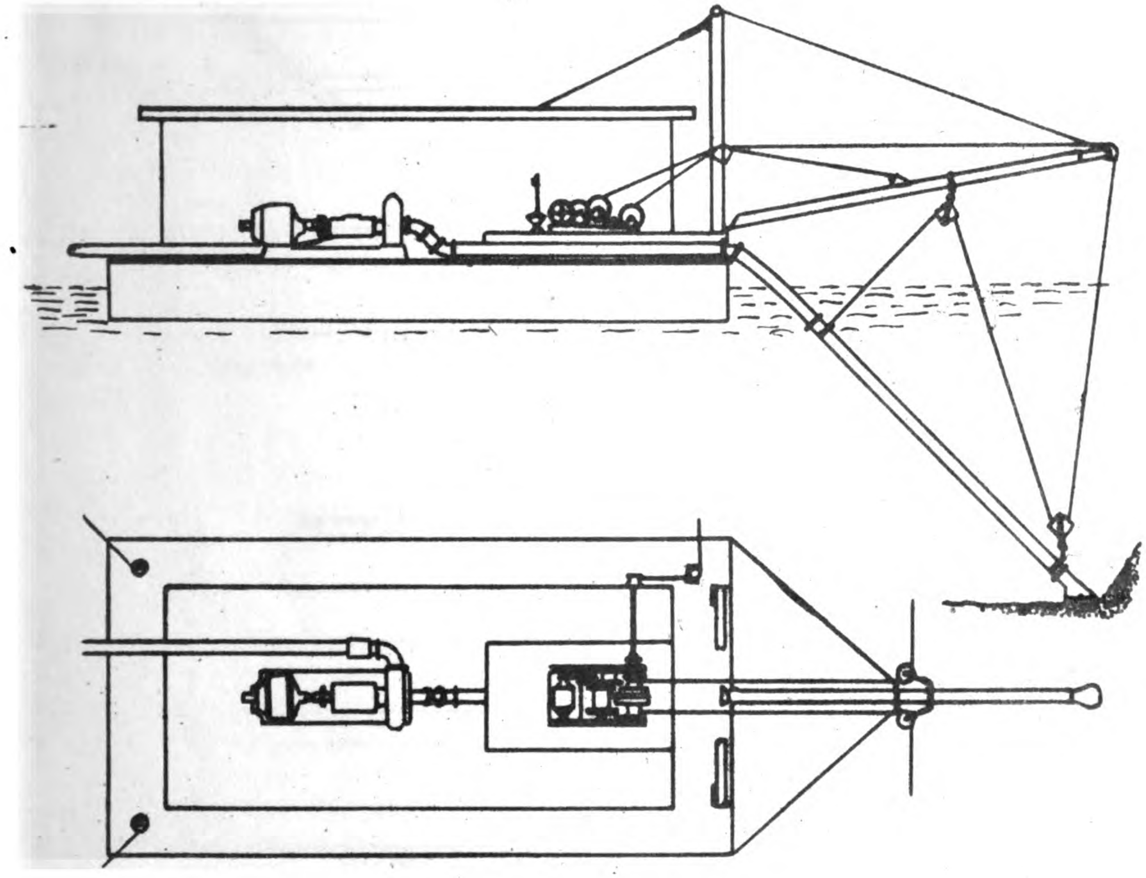

Figure 7.— Plan and elevation of plain hydraulic dredge.

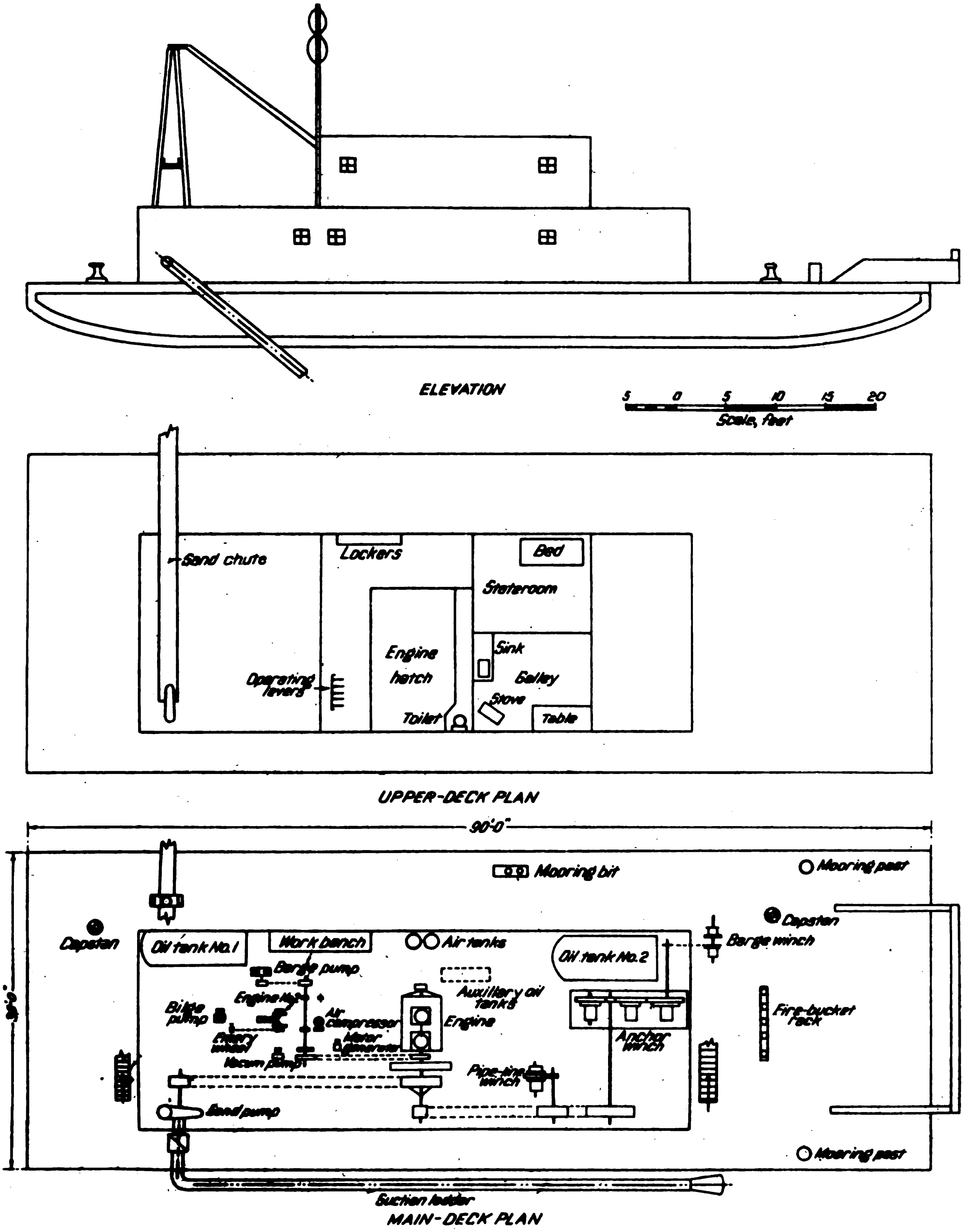

Figure 8.—Side elevation and deck plans of hydraulic dredge with quarters for crew.

If the suction pipe is lowered to the gravel bed while the pump is in operation the inrushing water will carry gravel with it provided that velocity is of sufficient intensity. Thus the hydraulic dredge excavates gravel by creating a vacuum within the suction pipe and thereby permitting natural forces to move the gravel to the pump.

In heavy or cemented gravel a mechanical stirring device is used ahead of the end of the suction pipe to break up the sand and gravel from its natural position so that the water can carry it into the pipe. These devices, however, do not do any actual excavating. They merely disintegrate the material so the water may convey it.

The hydraulic-dredge pump, however, has an added function. When the mixture of water and gravel has once reached the pump it is no longer affected by the atmospheric pressure on the original water surface. From here to the end of the discharge pipe the pump functions as a conveyor. By imparting velocity to the water it causes the water to transport the sand and gravel. The velocity attained depends upon the speed of revolution and the diameter of the pump impeller.

The dredge pump then has two distinct functions, one to create a partial vacuum by which to raise the gravel from the deposit to the pump and one to transport the gravel so raised to the end of the discharge pipe.

In performing both of these functions the pump must do more than actually lift and move the mixture of gravel and water. Water moving within a confined area such as the suction or discharge pipes creates friction with the inner walls of the pipe. Sand and gravel mixed with the water so moving greatly increase that friction. The pump must not only move the mixture, but it must move it against the friction which that very motion creates.

If the end of the discharge pipe is level with the pump, the pressure or head required to transport gravel is only that necessary to overcome friction in the pipe. If the end is below the pump the discharge pressure will be assisted by the action of gravity. If the end of the pipe is above the pump the pressure must be sufficient to overcome the action of gravity in raising the mixture of water and gravel that distance in addition to overcoming friction.

Thus it is evident that the hydraulic dredge pump must perform a number of functions which are assisted or retarded by natural phenomena. It must create conditions that permit natural forces to lift water and gravel from the deposit to the pump. In this it is assisted by the atmospheric pressure on the water surface. It is retarded first by the friction created by the material entering the suction, second by the friction created by the material traveling through the pipe, and third by the force of gravity.

It must force water and gravel through the discharge pipe. In this it is retarded by the friction created within the pipe and may be retarded or assisted by gravity according to whether the discharge outlet is above or below the pump. The latter seldom occurs in commercial practice.

Since the operation of an hydraulic dredge involves the movement of a liquid comprising 80 to 95 percent of water and 5 to 20 percent by volume of sand and gravel, obviously an understanding of the principles under which it operates must comprehend at least a fundamental knowledge of the laws of hydraulics and such modification of them as may be required by the handling of mixtures of sand, gravel, and water.

One of the important natural phenomena involved is the pressure of the atmosphere on the water surface. At sea level this is 14.7 pounds per square inch, and it extends equally in all directions.

For all practical purposes water is incompressible. Technically this is not true, but its compressibility depends upon its temperature and the amount of air in solution. The average change in volume is about 1 percent for a pressure of 3,000 pounds per square inch. Such a change due to pressure is too small to cause serious error in hydraulic calculations; hence it is disregarded.

Now since water is incompressible and the pressure of the atmosphere is equal on every square inch of the exposed surface, that pressure is automatically communicated to all material lying below the surface of the water without reduction. Therefore the particles of a submerged gravel deposit are at all times under a pressure equal to the weight of the atmosphere plus the weight of the water above them.

Atmospheric pressure decreases roughly 1/2 pound per square inch for each 1,000 feet of elevation above sea level; therefore the pressure available to assist the pump varies with the elevation of the water surface above sea level.

Atmospheric pressure is commonly measured by the mercurial barometer. If a glass tube of any convenient diameter and any length is closed at one end, filled with mercury to the exclusion of all air, and then inverted with the open end immersed in an open bowl of mercury a certain amount of the mercury in the tube will run out into the dish. Since the upper end of the tube is closed, a vacuum will be formed equal in volume to the mercury that has run out. This constitutes a mercurial barometer in its simplest form. The atmospheric pressure is measured in inches of mercury column between the surface of the mercury in the dish and the top of the column in the tube.

At sea level the column of mercury will stand 30 inches high. Therefore 14.7 pounds per square inch of atmospheric pressure will sustain a 30-inch column of mercury, or, as commonly expressed, 14.7 pounds atmospheric pressure equals 30 inches vacuum. For each 1,000 feet of elevation above sea level the mercury column drops approximately 1 inch. Therefore, since a 1,000-foot change in elevation equals a change of 1 inch in vacuum and 1/2 pound per square inch in atmospheric pressure, obviously if either be known at any particular point the other may be calculated from it.

Now if instead of mercury in the tube water is used and the open end is inverted and immersed in a tank of water, the column in the tube at sea level will stand 34 feet high. Therefore a 30-inch vacuum represents a 34-foot water column and each represents 14.7 pounds atmospheric pressure.

This means that if a pump were capable of producing a perfect vacuum at sea level it could draw water from a source the surface of which was 34 feet below the pump. In other words, the same pump at 30-inch vacuum could raise water against a 34-foot suction head.

Since a 30-inch vacuum corresponds to a 34-foot suction head, each inch of change in vacuum will correspond to 1.13 feet of change in suction head. Thus a pump required to draw water against a 28-foot suction head must be capable of producing 28 divided by 1.13 or 24.8 inches of vacuum. This is approximately the maximum lift obtainable in commercial practice.

The revolution of the pump impeller creates a partial vacuum within the pump casing and the suction pipe. The degree of vacuum created will depend upon the shape of the impeller vanes, the clearance space between impeller and pump casing, the speed of rotation, and the diameter of the impeller. These, of course, may vary greatly due to differences in design and construction of impellers and pumps.

A dredging pump is nothing more than a side-suction centrifugal pump, differing in construction from a water pump of that description only in that it has larger clearances through the impeller and casing to enable it to pass large-size solids and that the parts are extra-heavy and of wear-resisting materials to resist wear and abrasion occasioned by the material passing through.

In operation its function is to pump a stream of water into which is introduced a certain percentage of solids. The principal points of difference in operation between a dredging pump and a centrifugal side-suction water pump of similar size and characteristics are that the dredging pump has a somewhat lower mechanical efficiency, a lower drop in head for a given increase in capacity, and a tendency to overload the driver with an increase in capacity or drop in head. All of these differences are occasioned by the fact that a dredging pump must have larger clearances and ports to be able to handle large-size solids.

The first duty of the pump is to create a partial vacuum within its casing and suction pipe. The vacuum thus produced is used for several purposes, as follows: (1) To produce velocity in the water ascending the suction pipe; (2) to overcome friction in the suction pipe caused by the moving mixture; (3) to raise the sand, gravel, and water to the surface of the water; (4) to lift the mixture from the surface of the water to the center line of the pump; and (5) to overcome the inertia of the sand and gravel and cause it to move into the suction pipe.

One inch of vacuum corresponds to 1/2 pound per square inch of atmospheric pressure; therefore a pump capable of producing 20 inches of vacuum would create 10 pounds per square inch difference in atmospheric pressure between the interior of its suction and the surface of the water outside. Since the vacuum produced is independent of the diameter of the suction and discharge pipes, evidently the total static-pressure differential created by different sizes of pumps will vary as the square of the diameter, although the vacuum will remain the same. In other words, while the difference in static pressure per square inch remains constant for a constant vacuum, the total static pressure differential varies with the cross-sectional area of the suction pipe.

One inch of vacuum is equivalent to 1.13 feet of static head or water barometer. Therefore a pump capable of producing 25 inches of vacuum will make available 28.33 feet of static head to perform the five tasks enumerated above.

Table 30 presents the equivalent of static head for each inch of vacuum.

TABLE 30.- Static head in terms of vacuum

Vacuum, inches	Static head, feet	Vacuum, inches	Static head, feet
1	1.133	16	18.13
2	2.267	17	19.27
3	3.400	18	20.40
4	4.530	19	21.52
5	5.670	20	22.67
6	6.800	21	23.80
7	7.940	22	24.93
8	9.070	23	26.07
9	10.17	24	27.20
10	11.333	25	28.33
11	12.470	26	29.47
12	13.60	27	30.60
13	14.73	28	31.73
14	15.87	29	32.87
15	17.00	30	34.00

The degree of vacuum produced by a centrifugal pump is ascertained by reading the gage placed on the upper end of the suction pipe near the pump. A comparison of the observed reading with table 30 will show the static head available to perform the functions required of the pump.

Calculation of the force required to impart velocity to the water in the suction pipe follows the laws of falling bodies and may be reduced to a formula, as follows:

Let V represent the final velocity in feet per second, g the acceleration or 32.16, and h the static head in feet required to produce the desired velocity. Then

$$V^2 = 2gh \text{ and } h = V^2/2g.$$

From this formula the velocity head may be derived (disregarding friction) for any desired velocity. Experience has shown that sand and gravel pumps operate most efficiently at velocities ranging from 5 to 18 feet per second.

Table 31 gives the static head required to produce velocities within this range. The minimum velocity is probably too low for usual practice and would be permissible only under specific conditions. Modern practice tends toward increased velocity.

TABLE 31.- Static head required to produce various velocities

Velocity, feet per second	Static head required, feet	Velocity, feet per second	Static head required, feet
5	0.39	12	2.24
6	.56	13	2.63
7	.76	14	3.05
8	.995	15	3.50
9	1.26	16	3.98
10	1.55	17	4.50
11	1.88	18	5.04

The velocity required at any designated installation will depend upon several factors, including the size of gravel particles, length and elevation of discharge line, etc. Customarily the speed of the pump is set for velocities of 10 to 12 feet per second for sand and gravel excavation.

The head required to overcome friction in the suction pipe depends upon a number of factors, such as (1) the internal diameter of the pipe, (2) the condition of the internal surface of the pipe, and (3) the velocity of flow.

Various formulas for the determination of friction head have been prepared by different authorities on hydraulics. All are empirical in that they involve the use of constants determined by experiment to represent the effect of the condition of the interior surface of the pipe. For instance, the effect of seams and rivet heads in the interior of spiral pipe will be to increase frictional resistance above that required for new, smooth, cast-iron or steel pipe. Bends and curves will also increase frictional resistance, but since suction pipes are usually short and straight or have curves of large diameter the loss from this cause is usually disregarded.

As ordinarily published, tables of friction head are for clean water flowing in straight smooth pipes. A mixture of sand and gravel in the water will increase the frictional resistance, depending upon the size of the particles. Since the average size of particles will vary not only for every deposit but for each particular portion of any deposit, it is impossible to reduce this effect accurately to a formula that will apply to all conditions except by citing minimum and maximum limits which have been determined by experience.

Table 32 presents minimum and maximum friction heads for sand, gravel, and water mixtures at various velocities in various sizes of pipes. In sand and gravel dredging the losses due to friction appear to follow Williams and Hazens' tables for clear water based on their exponential formula using C = 100. In obtaining the figures for the frictional head for sand, gravel, and water mixtures Williams and Hazens' table has been increased 10 percent to obtain the minimum figure and 50 percent to obtain the maximum. The 10 percent increase is calculated to represent not over 10 percent sand with little gravel. More sand or a larger ratio of gravel requires a further increase up to the maximum of 50 percent. These are arbitrary estimates offered by the author. Accurate measurement of friction in sand and gravel dredging is difficult if not impossible for obvious reasons.

Since the maximum static head available with a pump creating a perfect vacuum is 34 feet, obviously the higher velocities in the smaller-diameter pipes would produce such high friction heads as to prevent their pumping sand and gravel at all, even neglecting other head losses.

TABLE 32.- Friction head for sand, gravel, and water mixtures in feet per 100 feet of straight, smooth pipe

(Calculated from Williams and Hazens' hydraulic tables; C = 100)

Velocity, feet per second	Pipe diameters, inches									
	4		5		6		8		10	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
5	4.6	6.3	3.6	4.9	2.9	3.9	2.0	2.8	1.6	2.2
6	6.0	8.1	5.0	6.8	4.0	5.5	2.9	4.0	2.2	3.1
7	8.7	12.0	6.7	9.1	5.4	7.3	3.9	5.3	3.0	4.0
8	11.0	15.1	8.6	11.7	6.9	9.4	5.0	6.8	3.8	5.2
9	13.9	18.9	10.6	14.5	8.5	11.6	6.2	8.4	4.7	6.5
10	16.7	22.8	12.9	17.6	10.4	14.1	7.5	10.2	5.7	7.8
11	20.0	27.3	15.4	21.0	12.7	17.3	8.9	12.1	6.9	9.4
12	23.4	32.0	18.1	24.8	15.0	20.4	10.5	14.2	8.1	11.0
13	27.3	....	21.0	28.7	17.3	23.6	12.2	16.2	9.4	12.8
14	31.2	....	24.2	33.0	19.8	27.0	14.1	19.2	10.8	14.7
15	....	....	27.4	....	22.5	30.6	16.0	21.8	12.2	16.6
16	....	....	30.8	....	25.3	34.5	18.0	24.6	13.7	18.7
17	....	....	34.4	....	28.4	....	20.2	27.4	15.4	21.0
18	....	....	....	....	31.4	....	22.3	30.4	17.2	23.4

Velocity, feet per second	Pipe diameters, inches									
	12		14		16		18		20	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
5	1.3	1.7	1.1	1.5	0.9	1.3	0.8	1.1	0.7	1.0
6	1.8	2.5	1.5	2.1	1.3	1.8	1.1	1.5	1.0	1.3
7	2.4	3.3	2.0	2.8	1.7	2.4	1.5	2.0	1.3	1.8
8	3.1	4.2	2.6	3.5	2.2	3.0	1.9	2.6	1.7	2.3
9	3.8	5.2	3.2	4.4	2.8	3.7	2.4	3.3	2.1	2.9
10	4.6	6.3	3.9	5.3	3.3	4.6	2.9	4.0	2.6	3.5
11	5.5	7.5	4.7	6.5	4.0	5.4	3.5	4.7	3.1	4.2
12	6.5	8.8	5.5	7.6	4.7	6.6	4.1	5.5	3.6	4.9
13	7.5	10.2	6.5	8.8	5.4	7.4	4.7	6.5	4.2	5.7
14	8.6	11.7	7.4	10.2	6.3	8.5	5.4	7.4	4.8	6.6
15	9.8	13.3	8.4	11.5	7.1	9.7	6.2	8.3	5.5	7.5
16	11.0	15.0	9.5	12.9	8.0	11.0	6.9	9.5	6.2	8.4
17	12.5	17.0	10.6	14.5	9.0	12.3	7.8	10.6	6.9	9.5
18	13.7	18.7	11.8	16.0	10.0	13.6	8.6	11.8	7.7	10.5

Since internal pipe friction is a function of the diameter of the pipe and the velocity of flow, any increase in diameter will decrease friction but will also reduce velocity. In some installations it is feasible to increase the size of the suction pipe and thereby reduce the velocity of the material entering the pump. This is not possible in all cases or to an unlimited degree because such a reduction in velocity may destroy the transporting power of the entering water.

Table 33 shows the capacity in cubic feet of various sizes of pipe for material traveling at different velocities.

The pump vacuum must next be utilized to lift the sand and gravel from the deposit to the surface of the water. For purposes of illustration the suction pipe may be considered as one leg of a U tube, the other leg being the body of water in which the suction is submerged. If the U tube is set upright with its open ends upward and water poured in one side, the water will come to rest at the same height in both legs irrespective of their length, inclination, or relative diameter. Similarly, while the pump is idle and the suction pipe submerged, the water inside is at the same elevation as that outside the pipe.

TABLE 33.- Capacity of pipe in cubic feet per minute at various velocities

Velocity, feet per second	Pipe diameter, inches									
	4	5	6	8	10	12	14	16	18	20
5	26	41	59	104	164	236	321	418	530	655
6	31	49	71	125	196	283	385	502	636	786
7	37	57	83	146	229	330	449	586	743	918
8	42	66	94	167	262	377	513	670	849	1,049
9	47	74	106	188	295	423	577	754	955	1,180
10	52	82	118	209	327	471	642	838	1,061	1,311
11	58	90	130	230	360	518	706	922	1,167	1,443
12	63	98	141	251	392	565	770	1,006	1,273	1,574
13	68	106	153	272	425	612	834	1,090	1,379	1,705
14	73	115	165	292	458	659	898	1,173	1,486	1,836
15	79	123	177	313	491	706	962	1,256	1,592	1,967
16	84	131	189	334	523	754	1,026	1,340	1,698	2,098
17	89	139	200	355	556	801	1,090	1,424	1,804	2,229
18	94	147	212	376	589	848	1,154	1,508	1,910	2,360

Now, if an impervious but frictionless partition is placed in the U tube at the center of the bend and water is placed in one leg to a height of 34 feet and mercury in the other to a height of 30 inches the two columns will retain these same heights even though the separating partition is free to move without friction. Mercury is 13.6 times as heavy as an equal volume of water or has a specific gravity of 13.6. It will be noted that the height of the water column (34 feet) is 13.6 times the height of the mercury column (30 inches). Therefore, when water is placed in one leg of the U tube, an equal weight of a liquid of different specific gravity in the other, and some means introduced to prevent their intermixing, the heights of the columns will vary inversely as their specific gravities.

Assuming the partition between the water and mercury has no weight and offers no frictional resistance to movement but still prevents either water or mercury to pass, then pressure may be applied to the water leg or pressure removed at the mercury leg and the two columns brought to the same level in each tube. The application of vacuum to the mercury tube illustrates the function of the pump in bringing sand and gravel to the surface of the water.

If instead of mercury one leg of the tube is filled with mixtures of sand, gravel, and water in which the quantity of sand and gravel ranges from 5 to 15 percent as ordinarily found in practice, one can calculate the feet of head required to bring the two columns to the same height. It is assumed of course that the sand and gravel remain dispersed and suspended in the water to form a homogeneous liquid.

Water weighs 62.5 pounds per cubic foot. Sand and gravel varies in weight but may be assumed to average 110 pounds per cubic foot. A cubic foot of sand and gravel, however, contains a certain amount of voids between the particles. An average void content may be assumed to be 40 percent. Five cubic feet of dry sand contains 40 percent voids or 2 cubic feet of air space. If this is mixed with 97 cubic feet of water the resulting volume will be 100 cubic feet, of which 5 cubic feet or 5 percent will be solids. Fifteen cubic feet of dry sand contains 40 percent or 6 cubic feet of voids. If this is mixed with 91 cubic feet of water the resulting volume will again be 100 cubic feet, of which 15 cubic feet or 15 percent will be solids. The weights of these two mixtures will be as follows:

Weight of mixtures

	5 percent solids		15percent solids	
	Pounds	Cu. ft.	Pounds	Cu. ft.
Water....................	5,937.5	95	5,312.5	85
Water in voids..	125	2	375	6
Sand and gravel	550	5	1,650	15
	6,612.5		7,337.5	

The weight of the mixture will range from 66 to 73 pounds per cubic foot or will have a specific gravity of 1.06 to 1.17. If equal weights of the mixture are placed in one leg of the U tube and clear water is placed in the other, the clear water column will be 1.06 to 1.17 times the height of the mixture column. This means that the water in the pond or lake will maintain a column of mixture of sand, gravel, and water in the suction pipe ranging from 94 to 85 percent of the vertical depth of submergence of the suction pipe. The head required to bring the mixture to the same level as the outside water is then 6 to 15 percent of the submergence, measured vertically, multiplied by the specific gravity of the mixture. Completing the multiplication, the head necessary to bring the mixture to the surface of the water will range from 6.4 percent of the vertical submergence for 5-percent solids to 17.5 percent for a 15-percent mixture.

Table 34 presents the head in feet required to bring the mixture to the surface for different percentages of solids and different vertical depths of submergence.

The pump, having raised the mixture of sand, gravel, and water to the surface of the pond, must continue and raise it to the center line of the pump. The distance from the center line of the pump to the water surface is the suction lift. As has been shown a perfect vacuum will raise clear water against a 34-foot suction head if friction is omitted from the calculation. The material handled by the pump, however, is not clear water but is heavier. As seen in table 34, the specific gravity will range from 1.01 for a mixture containing 1 percent to 1.46 for a mixture containing 40 percent solids. The head required to raise this mixture from the water surface is the suction lift in feet multiplied by the specific gravity of the mixture.

TABLE 34.- Feet of head required to bring sand, gravel, and water to the water surface

Solids, percent	Specific gravity	Vertical submergence, feet													
		2	4	6	8	10	12	14	16	18	20	22	24	26	28
1	1.01	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28
2	1.02	.04	.08	.12	.16	.20	.24	.29	.33	.37	.41	.45	.49	.53	.57
3	1.04	.08	.17	.25	.33	.42	.50	.58	.67	.75	.83	.92	1.00	1.08	1.17
4	1.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	1.01	1.11	1.21	1.31	1.41
5	1.06	.12	.24	.36	.48	.60	.72	.84	.96	1.08	1.20	1.32	1.44	1.56	1.68
6	1.07	.14	.28	.42	.56	.70	.83	.97	1.11	1.25	1.39	1.53	1.67	1.81	1.95
7	1.08	.16	.32	.48	.64	.80	.96	1.12	1.28	1.44	1.60	1.76	1.92	2.08	2.24
8	1.09	.18	.36	.54	.72	.90	1.09	1.27	1.45	1.63	1.81	1.99	2.17	2.35	2.53
9	1.10	.20	.40	.59	.79	.99	1.19	1.39	1.58	1.78	1.98	2.18	2.38	2.57	2.77
10	1.12	.24	.48	.72	.96	1.20	1.44	1.68	1.92	2.16	2.40	2.64	2.88	3.12	3.36
11	1.13	.26	.52	.78	1.04	1.30	1.56	1.82	2.08	2.34	2.60	2.86	3.12	3.38	3.64
12	1.14	.28	.56	.84	1.12	1.40	1.68	1.96	2.24	2.53	2.80	3.09	3.37	3.65	3.93
13	1.15	.30	.60	.90	1.20	1.50	1.80	2.09	2.39	2.69	2.99	3.29	3.59	3.89	4.19
14	1.16	.32	.64	.96	1.28	1.60	1.92	2.24	2.56	2.88	3.20	3.52	3.84	4.16	4.48
15	1.17	.34	.68	1.02	1.36	1.70	2.04	2.38	2.72	3.05	3.40	3.73	4.07	4.41	4.75
20	1.23	.46	.92	1.38	1.84	2.30	2.76	3.22	3.68	4.14	4.60	5.06	5.52	5.98	6.44
25	1.29	.58	1.16	1.74	2.32	2.90	3.48	4.06	4.64	5.22	5.80	6.38	6.96	7.54	8.12
30	1.32	.64	1.28	1.92	2.56	3.20	3.64	4.48	5.12	5.76	6.40	7.04	7.68	8.32	8.86
40	1.46	.93	1.86	2.79	3.72	4.65	5.58	6.50	7.44	8.37	9.30	10.20	11.20	12.10	13.00

Solids, percent	Specific gravity	Vertical submergence, feet											
		30	32	34	36	38	40	50	60	70	80	90	100
1	1.01	0.30	0.32	0.34	0.36	0.38	0.40	0.50	0.60	0.70	0.80	0.90	1.01
2	1.02	.61	.65	.69	.73	.77	.82	1.02	1.22	1.43	1.63	1.84	2.04
3	1.04	1.25	1.33	1.42	1.50	1.58	1.62	2.08	2.50	2.91	3.33	3.75	4.16
4	1.05	1.51	1.61	1.71	1.81	1.91	2.02	2.52	3.02	3.53	4.04	4.54	5.04
5	1.06	1.80	1.92	2.04	2.16	2.28	2.40	3.00	3.60	4.20	4.80	5.40	6.00
6	1.07	2.09	2.23	2.37	2.50	2.64	2.78	3.48	4.17	4.87	5.56	6.26	6.96
7	1.08	2.40	2.56	2.72	2.88	3.07	3.20	4.00	4.80	5.60	6.40	7.20	8.00
8	1.09	2.72	2.90	3.08	3.26	3.44	3.62	4.52	5.43	6.34	7.24	8.14	9.05
9	1.10	2.97	3.17	3.37	3.56	3.76	3.96	4.95	5.94	6.93	7.92	8.91	9.90
10	1.12	3.60	3.84	4.08	4.32	4.56	4.80	6.00	7.20	8.40	9.60	10.80	12.00
11	1.13	3.90	4.16	4.42	4.68	4.94	5.20	6.50	7.80	9.10	10.40	11.70	13.00
12	1.14	4.20	4.49	4.77	5.05	5.33	5.61	7.02	8.42	9.82	11.20	12.60	14.00
13	1.15	4.49	4.79	5.08	5.38	5.68	5.98	7.48	8.97	10.50	12.00	13.50	15.00
14	1.16	4.80	5.12	5.44	5.60	6.08	6.40	8.00	9.60	11.20	12.80	14.40	16.00
15	1.17	5.09	5.43	5.77	6.11	6.45	6.79	8.50	10.20	11.90	13.60	15.30	17.00
20	1.23	6.90	7.36	7.82	8.28	8.74	9.20	11.50	13.80	16.10	18.40	20.70	23.00
25	1.29	8.70	9.28	9.86	10.40	11.00	11.60	14.50	17.40	20.60	23.20	26.20	29.00
30	1.32	9.60	10.20	10.90	11.50	12.20	12.80	16.00	19.20	22.40	25.60	28.80	32.00
40	1.46	14.00	14.90	15.80	16.70	17.70	18.60	23.20	27.80	32.50	37.20	41.80	46.50

Table 35 presents the head required to raise mixtures of different percentages of solids through different distances of suction lift.

The head required to dislodge the sand and gravel from place and start it moving through the suction pipe is an indefinite quantity varying from moment to moment depending upon the size and shape of the particles and their degree of cementation in the deposit. The head available for this purpose is found by difference after subtracting the sum of all other requirements from the head available at the pump due to the vacuum produced.

To illustrate the use of the tables and the effect of varying conditions at a single installation, assume that an 8-inch pump is producing 25 inches of vacuum and is pumping a mixture of 10 percent solids at a velocity of 10 feet per second and discharging free into the air at the pump. Examples cited will use variations in suction head of 2 and 5 feet, of lengths of suction pipe of 50 and 100 feet, of diameter of suction of 8 and 10 inches, and of submergence of the gravel below the water surface of 15 and 40 feet. Only 8 combinations of these 4 variables are shown. It must be borne in mind also that the four conditions assumed in this example are also variable. Hence only a few of the possible combinations are worked out mathematically in table 36.

TABLE 35.- Feet of head required to raise sand, gravel, and water mixtures against suction lift

Solids, percent	Specific gravity	Suction lift, feet												
		1	2	3	4	5	6	7	8	9	10	12	14	16
1	1.01	1.01	2.02	3.03	4.04	5.05	6.06	7.07	8.08	9.09	10.10	12.12	14.14	16.16
2	1.02	1.02	2.04	3.06	4.08	5.10	6.12	7.14	8.16	9.18	10.20	12.24	14.28	16.32
3	1.04	1.04	2.08	3.12	4.16	5.20	6.24	7.28	8.32	9.36	10.40	12.48	14.56	16.64
4	1.05	1.05	2.10	3.15	4.20	5.25	6.30	7.35	8.40	9.45	10.50	12.60	14.70	16.80
5	1.06	1.06	2.12	3.18	4.24	5.30	6.36	7.42	8.48	9.54	10.60	12.72	14.84	16.96
6	1.07	1.07	2.14	3.21	4.28	5.35	6.42	7.49	8.56	9.63	10.70	12.84	14.98	17.12
7	1.08	1.08	2.16	3.24	4.32	5.40	6.48	7.56	8.64	9.72	10.80	12.96	15.12	17.28
8	1.09	1.09	2.18	3.27	4.36	5.45	6.54	7.63	8.72	9.81	10.90	13.08	15.26	17.44
9	1.10	1.10	2.20	3.30	4.40	5.50	6.60	7.70	8.80	9.90	11.00	13.20	15.40	17.60
10	1.12	1.12	2.24	3.36	4.48	5.60	6.72	7.84	8.96	10.08	11.20	13.44	15.68	17.92
11	1.13	1.13	2.26	3.39	4.52	5.65	6.78	7.91	9.04	10.17	11.30	13.56	15.82	18.08
12	1.14	1.14	2.28	3.42	4.56	5.70	6.84	7.98	9.12	10.26	11.40	13.68	15.96	18.24
13	1.15	1.15	2.30	3.45	4.60	5.75	6.90	8.05	9.20	10.35	11.50	13.80	16.10	18.40
14	1.16	1.16	2.32	3.48	4.64	5.80	6.96	8.12	9.28	10.44	11.60	13.92	16.24	18.56
15	1.17	1.17	2.34	3.51	4.68	5.85	7.02	8.19	9.36	10.53	11.70	14.04	16.38	18.72
20	1.23	1.23	2.46	3.69	4.92	6.15	7.38	8.61	9.84	11.07	12.30	14.76	17.22	19.18
25	1.29	1.29	2.58	3.87	5.16	6.45	7.74	9.03	10.32	11.61	12.90	15.48	18.06	20.64
30	1.32	1.32	2.64	3.96	5.28	6.60	7.92	9.24	10.56	11.88	13.20	15.84	18.48	21.12
40	1.46	1.46	2.92	4.38	5.84	7.30	8.76	10.22	11.68	13.14	14.60	17.52	20.44	23.36

TABLE 36.- Head required by various combinations of conditions

	A		B		C		D	
Suction lift..........feet	2		2		2		2	
Suction length..........do.	50		50		50		100	
Suction diameter..........inches	8		8		10		10	
Vertical submergence..........feet	15		40		40		40	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Static head required for velocity (10 ft. per sec. in 8 in. pipe equivalent volume in 10 in.) (tables 31-33)..........	1.55	1.55	1.55	1.55	0.64	0.64	0.64	0.64
Friction (tables 32-33)..........	3.75	5.10	3.75	5.10	1.25	1.75	2.26	3.46
Raising material to surface (table 34)..........	1.80	1.80	4.80	4.80	4.80	4.80	4.80	4.80
Raising material to the pump (table 35)..........	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
Total head required..........	9.34	10.69	12.34	13.69	8.93	9.43	9.94	11.14
Since the head available at the pump was 28.33 feet (25 inches vacuum), the head available to move gravel is..........	18.99	17.64	15.99	14.64	19.40	18.90	18.39	17.19

	E		F		G		H	
Suction lift..........feet	5		5		5		5	
Suction length..........do.	50		50		50		100	
Suction diameter..........inches	8		8		10		10	
Vertical submergence..........feet	15		40		40		40	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Static head required for velocity (10 ft. per sec. in 8 in. pipe equivalent volume in 10 in.) (tables 31-33)..........	1.55	1.55	1.55	1.55	0.64	0.64	0.64	0.64
Friction (tables 32-33)..........	3.75	5.10	3.75	5.10	1.25	1.75	2.26	3.46
Raising material to surface (table 34)..........	1.80	1.80	4.80	4.80	4.80	4.80	4.80	4.80
Raising material to the pump (table 35)..........	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60
Total head required..........	12.70	14.05	15.70	17.05	12.29	12.79	13.30	14.50
Since the head available at the pump was 28.33 feet (25 inches vacuum), the head available to move gravel is..........	15.63	14.28	12.63	11.28	16.04	15.54	15.03	13.83

By following the examples cited and substituting values for any local combination of conditions, the reader will be able to ascertain the range of possibilities for his particular installation.

THE PUMP AS A TRANSPORTING AGENT

In the previous discussion the function of the pump has been to excavate gravel and sand and bring them to the pump itself. Sand and gravel pumps as usually installed must do more than this. They must transport the mixture of sand, gravel, and water beyond the pump through a discharge pipe to the barge or treatment plant. This involves calculation of the friction set up within the discharge pipe and the elevation of the point of discharge above the pump.

The friction in the discharge pipe is calculated in the same way as in the suction pipe, hence table 32 may be used to ascertain the total friction head necessary for any length of discharge pipe for minimum and maximum conditions at different velocities of flow.

When a pump discharges through an elevated discharge pipe, it must lift the material pumped through a vertical distance equal to the difference in elevation of the center of the pump and the end of the discharge. The head required to do this is equal to the vertical distance in feet.

POWER REQUIREMENTS

The power required to operate a sand and gravel pump may be computed from the formula

$$P = QWH/33{,}000$$

in which P equals the theoretical horsepower, Q the quantity of material handled in cubic feet per minute, W the weight of a cubic foot of the material handled, and H the total head against which the pump is working, and 33,000 the foot-pounds per minute corresponding to 1 hp.

The quantity of material handled in cubic feet per minute depends upon the diameter of the discharge pipe and the velocity of flow. This may be read directly from table 33.

The weight of a cubic foot of the material handled is the product of the weight of a cubic foot of water and the specific gravity of the material handled. Specific gravities of mixtures with varying percentages of solids are given in table 35, and a cubic foot of water weighs 62.5 pounds.

The total head against which the pump must operate is the sum of the suction head, the static head, and the friction head.

The suction head is obtained by reading the vacuum gage on the suction pipe close to the pump and converting this into feet by reference to table 30.

The static head with the usual arrangement of discharge pipe is the vertical height of the end of the discharge pipe above the center of the pump.

The friction head may be calculated from table 32 for various lengths of pipe.

As an example, assume the same 8-inch pump producing 25 inches of vacuum is pumping 10 percent solids at 12 feet per second through an 8-inch discharge pipe 200 feet long, the end of which is 20 feet above the pump.

Table 33 shows that the quantity of material delivered from an 8-inch pipe at a velocity of 12 feet per second is 251 cubic feet per minute, or Q in the formula.

From table 35 the specific gravity of a mixture containing 10 percent solids is 1.12 and the weight W of a cubic foot will be 62.5 times 1.12 or 70 pounds.

	Feet
Suction head (from table 30)	28.33
Static head	20.00
Friction head (from table 32 it will range from 10.5 to 14.2 feet per 100 feet of discharge pipe. Assume an average of 12.35 feet)	24.70
Total head	73.03

Solving in the equation then

$$P = 251 \times 70 \times 73.03/33{,}000 = 39 \text{ hp.}$$

Sand and gravel pumps by actual test have shown efficiencies as high as 78 percent. Experience, however, shows that when computing the rating of the necessary motive power to apply to a given set up, it is best to assume 50 percent efficiency and select the drive accordingly. Therefore, the theoretical or water horsepower in this case would be 39, and the brake horsepower or motor rating would be 78 or 80.

Operating Limitations

For the same reasons that it is impossible to tabulate pump capacities it is also impossible to tabulate operating limitations.

As has been shown in the discussion of the characteristics of dredging pumps the depth from which gravel may be pumped depends largely upon the friction in the suction pipe. This involves computation based principally on the length and diameter of the suction pipe, either of which may be altered at will.

The ability of a pump to overcome suction head is directly proportional to the amount of vacuum of which it is capable, and this in turn depends upon the amount of clearance between the impeller vanes and the pump casing, which is a matter of individual pump design. The only positive statement regarding all pumps that can be made in this connection is as follows: In order to pump gravel the vacuum produced by a pump must be sufficient to overcome the total suction head and is limited to the portion of the natural head produced by atmospheric pressure that the pump is capable of utilizing, that is, the vacuum it is able to develop.

The space between impellers and casing is designed for each particular pump size and may vary with the design of various manufacturers. Except within a very small range it is not subject to change by increasing impeller diameter in any individual pump. The clearance will generally permit the passage of material ranging in diameter from 60 to 75 percent of the diameter of the pump intake. By this is meant the suction opening of the pump itself and not the suction pipe. The approximate maximum limits of material permissible for various sizes of pumps follow:

Size of pump, inches	Maximum size of particle, inches
4	2.375
6	4.125
8	5.875
10	7.500
12	9.25
15	11.00
20	14.00

It is obvious that the size of the average particle or the size of the maximum particles in a deposit will affect the size of the pump to be used. For instance, a deposit containing an appreciable percentage of boulders averaging 6 inches in diameter would not warrant the installation of a pump with less than a 10-inch suction opening and might even require a 12-inch opening. Any deposit containing boulders averaging 6 inches in diameter will have a considerable quantity of larger size, hence a 10-inch pump with 7.5-inch clearance would suffer from frequent blocking in the suction line. This might occur even in a 12-inch pump. If boulders of this size form an important portion of the deposit it would be preferable to increase the pump size to 20 inches. The reason for this is that the diameter of the suction opening to minimize stoppage should be at least three times the diameter of the average large particles. If the ratio of boulders to fine particles is too great some other type of dredge is preferable. It is difficult to set an arbitrary limit on this ratio, but ordinarily a pump would be entirely unsuitable for excavating a deposit in which 10 percent of the gravel is larger than the clearance limit of the pump. This rule applies even though the dredge is equipped with a traveling or rotary screen. Without such auxiliary equipment the clearance limit of the pump should exceed the diameter of the largest particles, except of course that of the occasional large boulders common to most deposits.

Hydraulic pumps without supplementary equipment such as traveling or rotary screens cannot be used to excavate cemented gravel. As shown in the previous discussion of pump functions the force which moves the sand and gravel into the pump suction is the static head available after friction and other suction losses have been provided for. Even at a maximum this is incapable of destroying the bond between particles of cemented material or even consolidated hardpan. By the use of traveling or rotary screens hardpan or cemented gravel of considerable firmness can be broken up by the moving blades of the screen, and when so disintegrated the pump can excavate it. The degree of cementation or consolidation which can be broken up with such auxiliary equipment depends upon the mechanical construction and strength of the screens, a discussion of which is not within the scope of this paper.

A dredge pump should at all times be placed as near the surface of the water as possible. This reduces the suction lift required to bring the material from the water surface to the pump. As is shown by the examples cited, this item is an important one and may even exceed the effect of friction in the suction pipe in the consumption of available vacuum. No arbitrary limit other than that due to atmospheric pressure can be placed on the elevation of the pump above water level because of the relative effect of other factors. However, dredge pumps as a rule do not operate effectually if placed more than 6 feet above the surface of the water.

The depth from which a dredge pump can excavate gravel is affected by a number of variable factors. The head required to overcome friction in the suction pipe varies directly with the length of the pipe, the velocity of flow in the pipe, and the percentage of solids in the mixture handled. It varies inversely with the diameter of the suction pipe. The head required to bring the mixture to the surface of the water varies directly with the percentage of solids in the mixture or its specific gravity.

Since each of these factors influences the dredging depth, table 37 has been compiled to illustrate their effect in limiting dredging depth. Combination of conditions are given from A to K in the table. In all combinations, however, it is assumed that the pump is capable of producing 25 inches of vacuum or 28.33 feet of suction head. It is also assumed that at least 10 feet of head will be required to move the material from the deposit into the end of the suction pipe. This is probably a rather conservative allowance, and more would be necessary for coarse or compacted material. In each example it is therefore assumed that there are 28.33 -10 = 18.33 feet of head available at the pump to overcome friction in the suction pipe, to bring the mixture to the surface of the water, and to impart velocity to the material handled. Head for suction lift is eliminated by assuming that the center line of the pump is level with the surface of the water. It is further assumed that a minimum velocity of 5 feet per second is necessary to move sand and that the maximum velocity permitted for gravel is 15 feet per second.

In studying this table, it must be borne in mind that the computations are theoretical, that no head is computed for suction lift, and that the length of the suction pipe is roughly taken as 1 1/4 times the vertical submergence. The vertical submergence shown in each example is a maximum.

TABLE 37.- Maximum dredging depth for various combinations of conditions

	Feet
Assumed vacuum at pump, 25 inches	28.33
Assumed minimum entrance head required at end of suction	10.00
Head available for velocity, friction, and submergence	18.33

Combination and feet of head	Diameter of pump, inches	Diameter of suction, inches	Per-cent of solids	Velocity of discharge, feet per second	Velocity of suction, feet per second	Submergence, feet	Suction length, feet	Total head required	Surplus head	Capacity, cubic yards per hour
A	8	8	15	15	15	33	41			104
					[1]3.5	[2]5.6	[3]8.94	18.03	0.30	
B	8	8	12	10	10	60	75			56
					[1]2.24	[2]8.42	[3]7.05	17.71	0.62	
C	8	8	5	5	5	200	250			11.5
					[1]0.39	[2]12.00	[3]5.00	17.39	0.94	
D	8	12	15	15	6.63	80	100			104
					[1]0.69	[2]13.60	[3]3.00	17.29	1.04	
E	8	12	12	10	6.63	100	125			56
					[1]0.69	[2]14.00	[3]3.36	18.05	0.28	
F	16	16	15	15	15	50	65			419
					[1]3.5	[2]8.5	[3]6.3	18.30	0.03	
G	16	1	12	10	10	80	100			225
					[1]2.24	[2]11.2	[3]4.2	17.64	0.69	
H	16	16	5	5	5	250	315			46
					[1]0.39	[2]15.00	[3]2.84	18.23	0.10	
I	16	20	12	10	7.67	95	120			225
					[1]0.92	[2]13.3	[3]3.84	18.06	0.27	
J	6	6	12	10	10	50	65			31.5
					[1]2.24	[2]7.02	[3]8.45	17.71	0.62	
K	6	8	12	10	5.67	95	120			31.5
					[1]0.51	[2]13.3	[3]3.96	17.77	0.56	

[1] Table 31.

[2] Table 34.

[3] Table 32.

Considered purely as a transporting agent the pump is limited only by the speed permissible in its mechanical construction and the strength of materials of which it and the discharge line are composed. Increased demands for delivery head are met by increasing the speed of revolution and the diameter of the impeller. Obviously these could be increased to such a point that the pressure produced would be more than the construction of the pump would withstand. Centrifugal pumps handling water only may be built for very high pressures, but for such purposes they are usually constructed in stages. That is, two or more pumps or stages are constructed on one drive shaft and within the same casing so that the discharge from the first pump or stage becomes the intake for the next. Single-stage water pumps have been built for heads as high as 400 feet, but these are exceptional. Dredge pumps are seldom built for more than a single stage. Instead booster pumps are added in the discharge line because of simplified construction, reduced pressure on the line, and reduction of internal wear coincident with reduced pressure when handling mixtures of sand and gravel in the water. The construction of modern dredging pumps provides for a range of operating speeds consistent with the safety factor of the strength of material used and the cost of construction. Impellers can be varied in a particular pump as much as 15 percent of their diameter. Obviously a pump of small impeller diameter could be operated at a higher speed and would entail less construction cost than one of large diameter with its more massive rotating parts. Moreover, an increase in speed for any particular pump can be obtained by increasing the drive ratio or changing motors. Increasing the available head by increasing impeller diameter, on the other hand, involves replacing one pump with another. For example, a pump having a 24-inch impeller and operating at 550 r.p.m. will produce a total head of 61.75 feet. (See table 38.) To increase the head to 100 feet an increase to 700 r.p.m. would be necessary and is within mechanical bounds. To retain the same number of revolutions per minute but obtain the increased head would require an increase in impeller diameter to 31 inches. This also is within economical mechanical construction but would necessitate a new pump and increase the headroom required.

On the other hand, if 200 feet of head were necessary the speed of the 24-inch impeller would have to be increased to 1,000 r.p.m., which might be more expensive than changing to a new pump having a 36-inch impeller and operating at a little more than 650 r.p.m.

Any increase, within operating limits, of the head against which a pump must operate results in a loss of volume pumped or capacity unless the pump speed is increased. The efficiency of the pump is thereby lowered. By increasing the speed to retain the same capacity against the higher head more power will be required, but the original efficiency may be retained.

On the other hand, a decrease in the head against which a pump operates results in an increased volume pumped but does not necessarily increase efficiency, because more power is required to move the greater quantity of material pumped.

These apparently antagonistic phenomena are due to the structural characteristics of centrifugal pumps. As previously mentioned the centrifugal pump imparts velocity to the material pumped by revolving the impellor blades within the pump casing. The impeller does not fit the inside of the casing in a tight joint as in plunger pumps. Consequently there is a constant slippage around the impellers through the clearance between them and the casing. Therefore as the delivery head increases, the back pressure or pressure against which the pump must operate increases. As this pressure increases the slippage within the pump increases, hence the loss in volume pumped. If the delivery pressure of a plunger-type pump is increased by closing a valve in the discharge line the pressure will build up to such a point as to exceed the bursting strength of pump or pipe line. On the other hand, if the discharge head on a centrifugal pump is increased by closing a similar valve the pressure will increase to such a point as to cause the slippage around the impellers to equal the volume pumped, and the pump merely rotates the water within its casing.

In a reduction of discharge head, as, for instance, a break in the pipe line, the reduction in pressure reduces the slippage between impeller and casing and thereby increases the volume pumped. This increase in volume demands greater power, and there is therefore a tendency to overload the driving engine which must be guarded against by proper protecting devices.

It is obvious that the performance of an individual dredge pump is influenced and limited by its internal clearance, in other words, by the design of the individual unit. Since this is a matter of the ideas and convictions of the designing engineers of various manufacturers, it is not discussed in this paper.

There are certain general exceptions however which may be noted. For example, a recent inovation is a dredge pump designed to be lowered beneath the water surface with the suction pipe. The effect is to reduce the vacuum necessary to (1) overcome frictional resistance in the suction pipe, (2) bring the mixture of water and gravel to the water surface, and (3) overcome suction lift.

There is therefore a greater portion of the vacuum available to bring material from the deposit to the suction pipe. The head due to submergence also acts to bring material to the suction pipe with this type of pump. The frictional resistance and other factors released from the influence of the pump vacuum are not eliminated, however, but they are transferred to the discharge or transporting function of the pump.

Another application of the centrifugal pump for dredging operations employs the pump to pump water only, at high pressure through a conical nozzle. This nozzle is placed within and near the lower end of the suction pipe. As this high-pressure water is released and rushes up the suction pipe, it creates a vacuum permitting static pressure to force gravel into the end of the suction. It also acts as a conveyor to carry the gravel up the suction pipe to the discharge. In principle this type of dredge is a water ejector on a large scale, or, in other words, another type of submerged pump. A detailed description is contained in Bureau of Mines Information Circular 6580, Methods and Costs of Mining and Preparing Sand and Gravel at the Plant of the Ward Sand and Gravel Company, Oxford, Mich.

AUXILIARY EQUIPMENT

Except in the few instances of self-contained lake- and ocean-going vessels, hydraulic dredges are not self-propelled. Ordinarily dredges operating in rivers, lakes, or along ocean shores must be moved from one digging location to another by towboats or tugs. This is frequently necessary in artificial ponds which have become enlarged by long-continued excavation.

Wherever the distance from digging point to plant is short the dredge pump is called upon to transport as well as dig gravel. As this distance increases auxiliary pumps may be installed in the discharge line. When this is done care is necessary to see that the intake of the booster pump is under some slight pressure from the discharge of the digger. At times, more than one booster has been employed, but ordinarily this increases the cost of power beyond economic limits. In other words, it is usually cheaper to pump short distances, but for long hauls towboats and barges or cars and locomotives are more economical.

Any type of transportation unit may be employed to serve a hydraulic dredge. Usually, however, pump dredges deliver direct to plant through pipe lines or to barges which are towed to the plant. Sometimes, however, dredges are used to dig and deliver gravel to a designated point in the river from which it may be picked up by an auxiliary dredge, clamshell, dragline, or power scraper. In other instances, the digger delivers to storage on the river bank from which other types of equipment carry it to the plant. The transfer from dredge discharge to other equipment must provide some means of dewatering except when a second dredge is the auxiliary unit.

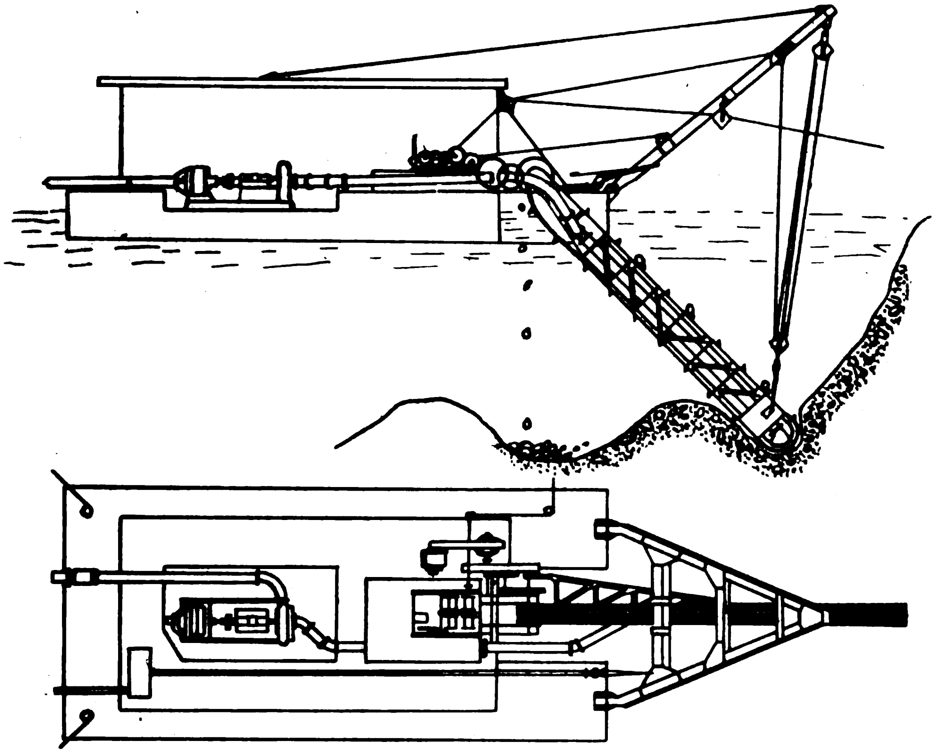

Figure 9.— Plan and elevation of hydraulic dredge with traveling screen.

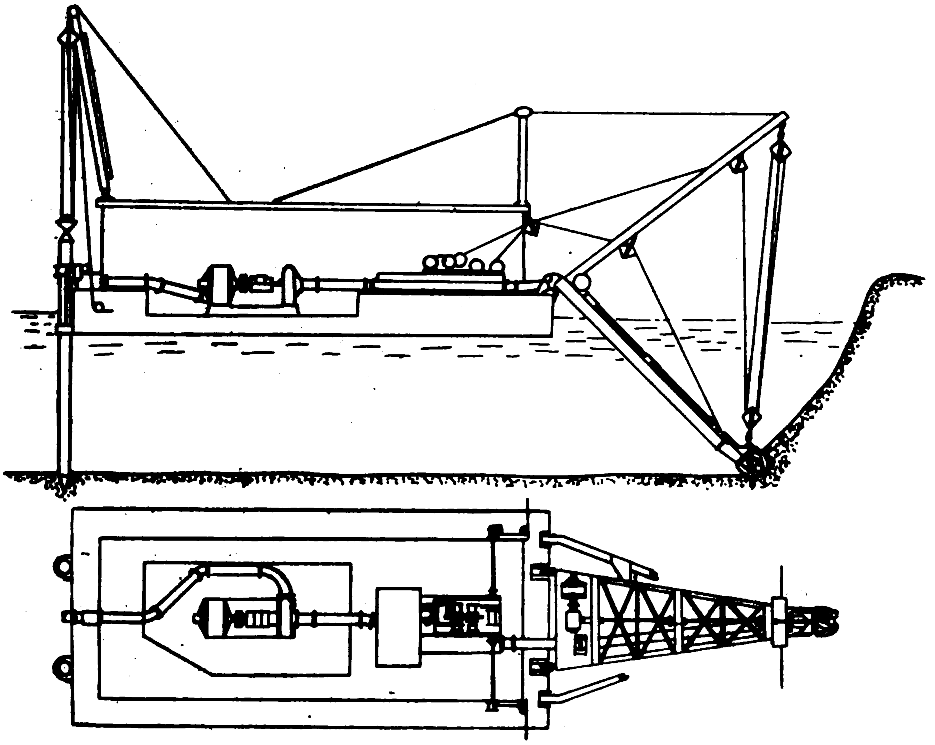

Figure 10.— Plan and elevation of hydraulic dredge with cutter head.

Another type of auxiliary equipment employed by the hydraulic dredge is, the traveling screen or rotary cutter head placed at the end of the suction pipe. These aids are used to break up cemented gravel or hardpan and so disentegrate them that the suction can pick them up. In addition to performing this function it also acts as a screen around the end of the suction to prevent the entrance of boulders too large for the pipe.

One type of traveling screen is constructed similar to a double-chain bucket elevator. (See fig. 9.) In place of the buckets heavy steel bars are used, spaced so as to permit the passage between them of only such material as can be handled by the pump. The screens are supported by a boom which also carries the suction pipe. The construction is such that the screen travels downward under the suction pipe, around the lower end over large sheaves, and back up on the upper side of the boom. In passing around the lower sheave the bars break up the gravel so the suction can pick it up.

Another type consists of a rotary head enveloping the end of the suction pipe and driven by a shaft paralleling and attached to the suction pipe. (See fig. 10.) Motive power for the cutter is applied from the dredge deck by auxiliary equipment. The blades on this type of cutter are helical in shape and are spaced so as to prevent oversize material from reaching the suction.

In some instances where the deposit is not densely packed a hydraulic jet is brought down with the suction pipe. Water under high pressure is forced through this jet and against the deposit. Its purpose is to disintegrate the material.

Hydraulic jets also are often used to wash down and cave the bank which the dredge suction is undermining. Without their use dangerous conditions might arise in which large sections caving from the bank might bury the suction line or even cause sufficient surge to swamp and sink the dredge.

No hydraulic dredge pump can by itself start water or gravel up the empty suction pipe. Unlike water, air can be compressed or expanded. Expansion of the air within a confined cylinder by extraction creates a partial vacuum within that cylinder. If one end of that cylinder is open, permitting the entrance of water, which, in turn, is subject to atmospheric pressure, water will enter the cylinder to the extent the air is extracted. A plunger pump with pistons in close contact with the cylinders can extract air from a suction pipe and thereby cause water to flow up the pipe and into the pump. In other words, such a pump can prime itself. The dredge pump on the other hand cannot pump air because of the space between impeller blades and casing. When a dredge pump is revolved without first being filled with water it simply revolves the air within the pump casing. Therefore dredge pumps must have some auxiliary means of priming. A centrifugal pump used for pumping water only is usually provided with a foot valve at the lower end of the suction pipe. This valve permits water to flow into the suction but prevents it from flowing out. A small plunger pump may be connected so as to pump water into the casing and suction pipe of the centrifugal pump and fill them. When so filled the centrifugal pump is primed and when revolved will pump water.

Dredge pumps, however, do not have foot valves because of the abrasion to which they would be subjected when pumping gravel. The usual procedure in priming a dredge pump is to attach an air pump to the pump casing and extract the air from pump and suction pipe. To do this a tight valve must be placed in the discharge line of the dredge pump. Then as the air is extracted it is replaced by water from the submerged open end of the suction pipe. As soon as the pump casing and suction line are filled with water the dredge pump is started and the valve in the discharge line opened.

All types of centrifugal dredge pumps must have some sort of priming device, but the particular kind may vary for different conditions.

In addition to the auxiliary equipment mentioned, hydraulic dredges are frequently equipped with winches, cables, and anchors with which they may be manipulated from side to side or forward or backward to keep the suction in the most advantageous position for digging. In some dredges these winches and anchors are displaced by wooden or steel spuds. On hydraulic dredges there are usually two spuds used, one on each stern corner of the hull.

The spuds are heavy piles with pointed lower ends which may be raised or lowered by winch and cable. When the hull is brought to the digging position one spud is dropped to the bottom and acts as a pivot around which the dredge is rotated while digging. The position of the hull may be shifted by using the second spud. The hull is then rotated alternately around each spud and thus "walked" to the new position. By alternately raising and lowering the two spuds, the dredge can thus be "walked" across the bottom in any direction.

Hydraulic dredges may be operated by steam, gasoline, Deisel, or electric power or various combinations of these types as prime movers. Steam power requires larger hulls to accomodate the engine and boilers but provides flexibility as excess power or speed may be applied when needed. Boilers must be fired and steam pressure raised before the dredge can operate.

Gasoline or Deisel power plants require less space and therefore smaller hulls and are instantly available for power as soon as put in motion. Variable speed may be applied through gear or other reduction connection between motor and pump. In many localities Deisel power is cheaper than any other, but this depends largely upon local fuel costs.

The continuous operation of dredge pumps makes them peculiarly fitted for connection to any type of power plant which operates at a uniform rate. This includes either gasoline, oil, Deisel, or electric motor. With electric power, variable-speed motors may be direct-connected to the pump shaft or constant-speed motors connected through variable-speed reducers. Primary electric power may be used on a dredge located in an artificial pond in which no extensive shifting from place to place is involved. With such primary power the power cables are usually wound on a reel at the stern of the dredge for flexibility. Where it is necessary to move the dredge frequently from place to place the primary-power plant may be steam or Deisel, driving a generator which in turn supplies electric power to the pump motor and other auxiliary equipment. Such installations however are not common. Ordinarily steam or Deisel power is used direct.

CAPACITY

The capacity of dredge pumps, is really the most difficult question of all, and it cannot be treated otherwise than through empirical figures and rules. Capacity is, of course, a function of the volume of water being pumped and the percentage of solids carried in suspension. Both of these vary continuously, and each depends on a number of factors. The percentage of solids carried in suspension varies with the skill of the operator, the character of the material, the velocity of flow through the pipe line, and the length and character of the pipe line. Naturally, a higher percentage of sand is carried than of gravel, and a higher percentage of material can be carried at high velocity than at low velocity. Moreover, a higher percentage can be carried of a given material at a given velocity when pumping through a short pipe line than when pumping through a long pipe line, especially one having long horizontal stretches of pipe in which the material settles to the bottom of the line and plugs up the pipe. A skilled operator will, of course, feed the material uniformly into the suction and will average a higher percentage of material than an unskilled operator.

The velocity of flow through the pipe line, on the other hand, will vary with the length of the pipe line, the lift, the pump speed, the percentage of solids, and the nature of the solids. Given constant speed, lift, and length of pipe line, the velocity of flow will vary with the percentage of material, being higher when carrying a smaller percentage of material, and vice versa, and being higher for the same percentage of materials which are less sharp and abrasive because of less friction against the sides of the pipe.

Under the circumstances, it is impossible to arrive at any exact formula for determining the output, which can only be arrived at by figuring each case individually and taking into account all the different factors involved.

As a first step in calculating capacity the total head of which the pump is capable must be known. This will vary as the square of the speed for a given diameter of impeller or as the square of the diameter of the impeller for a given speed, and may be roughly expressed by the formula

$$H = V^2/2g,$$

where H is the total head developed in feet, V is the velocity in feet per second, and g is acceleration due to gravity or 32.16.

V in this case is the peripheral speed of the impeller and may be expressed in feet per second as

$$\text{R.p.m.}/60 \times 3.1416\, D/12,$$

where D equals the diameter of the impeller in inches.

Substituting this value for V in the original formula it becomes

$$H = (\text{R.p.m.} \times 0.262D/482)^2.$$

This formula is theoretically correct, but in practice the actual head obtained will be 10 to 30 percent higher, depending upon the design of the impeller. A working mean between these variations is usually taken at 20 percent, hence the formula becomes

$$H = 1.2\ (\text{R.p.m.} \times 0.262D/482)^2, \text{ or}$$

$$H = (\text{R.p.m.} \times D/1680)^2.$$

Table 28 has been compiled in accordance with this formula to show the head developed by pumps using impellers of varying diameters running at various speeds.

Thus a 24-inch impeller operating at 500 r.p.m. from table 38 gives a head of 51.0 feet.

Referring now to the various combinations assumed for the 8-inch pump in table 36, assume that it had an impeller 24 inches in diameter and was operated at a speed of 535 r.p.m. From table 38 by interpolation the total head developed by the pump would be 58.52 feet. It is true that to produce vacuum this pump must revolve and that the vacuum produced will increase with the speed of the pump up to a certain point. To this extent the speed of the pump determines the vacuum. Dredging pumps must have a certain clearance area between the impellers and the pump casing to permit the passage of gravel. This area permits slippage of the liquid around the impellers within the pump. Thus, when the pump speed is such as to impart the maximum vacuum of which that particular pump is capable any increase in speed does not necessarily increase the vacuum produced.

In the original example it was assumed that the pump was capable of producing 25 inches of vacuum. From table 36 it is apparent that the static head or vacuum available for the several combinations ranged from 11.28 to 19.40 feet. These heads are sufficient to bring sand to the suction and will be enough for uncemented gravel. Therefore the vacuum assumed for the pump is sufficient to bring the sand and gravel to the pump.

The head available due to the speed and diameter of the impellers, less that required to produce vacuum, can then be used for transporting the water, sand, and gravel through the discharge pipe. The available head is then 58.52 - 28.33 = 30.19 feet.

TABLE 38.- Total head in feet developed by dredge pumps.

Speed,	Diameter of impeller, inches											
r.p.m.	12	18	20	22	24	26	28	30	32	34	36	48	60
100	0.51	1.15	1.42	1.72	2.04	2.40	2.78	3.19	3.63	4.10	4.59	8.16	12.75
125	.80	1.80	2.22	2.68	3.19	3.76	4.34	4.98	5.67	6.40	7.18	12.75	20.00
150	1.15	2.58	3.19	3.86	4.59	5.38	6.25	7.18	8.16	9.20	10.33	18.35	28.70
175	1.56	3.52	4.33	5.25	6.25	7.34	8.53	9.76	11.10	12.50	14.00	25.00	39.10
200	2.04	4.37	5.66	6.86	8.16	9.60	11.10	12.75	14.50	16.40	18.35	32.70	51.00
225	2.58	5.80	7.18	8.70	10.30	12.10	14.10	16.10	18.40	20.75	23.20	41.25	64.50
250	3.19	7.17	8.85	10.70	12.75	15.00	17.35	19.90	22.65	25.60	28.70	51.00	79.70
275	3.86	8.68	10.70	12.97	15.45	18.10	21.00	24.10	27.40	31.00	34.80	61.80	96.50
300	4.53	10.30	12.75	15.45	18.40	21.60	25.00	28.65	32.70	36.80	41.40	73.50	120.00
325	5.40	12.10	15.00	18.10	21.60	25.35	29.40	33.70	38.40	43.40	48.75	86.20	135.00
350	6.25	14.05	17.35	21.00	25.00	29.35	34.00	39.00	44.50	50.20	56.25	100.00	156.00
375	7.18	16.10	19.90	24.10	28.70	33.70	39.10	44.80	51.00	57.75	64.50	115.00	180.00
400	8.17	18.40	22.70	27.50	32.70	38.30	44.50	51.00	58.00	65.60	73.50	131.00	204.00
425	9.22	20.75	25.60	31.00	36.80	43.30	50.00	57.50	65.60	74.00	83.00	147.00	
450	10.35	23.20	28.70	34.80	41.40	48.50	56.25	64.50	73.40	83.00	93.00	165.00	
475	11.50	25.45	32.00	38.80	46.20	54.00	62.50	72.00	82.00	92.00	104.00	184.00	
500	12.80	28.70	35.40	42.90	51.00	59.75	69.30	79.70	90.70	102.00	115.00	204.00	
550	15.45	34.80	43.00	51.80	61.75	72.30	84.00	96.50	110.00	124.00	139.00		
600	18.40	41.30	51.00	61.80	73.50	86.40	100.00	115.00	130.00	147.00	165.00		
650	21.50	48.50	60.00	72.50	86.50	101.00	117.00	134.00	154.00	173.00	194.00		
700	25.00	56.25	69.50	84.00	100.00	117.00	136.00	156.00	179.00	200.00	225.00		
750	28.80	64.50	79.50	96.50	115.00	135.00	156.00	180.00	204.00				
800	32.60	73.50	90.00	110.00	130.00	153.00	178.00	203.00					
850	36.80	83.00	102.00	124.00	147.00	173.00	200.00						
900	41.30	93.00	115.00	139.00	165.00	194.00	225.00						
1,000	51.00	115.00	142.00	171.00	204.00								
1,250	80.00	180.00	222.00	268.00									
1,500	115.00	254.00											
1,750	156.00												
2,000	204.00												

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[1] In general practice maximum pumping efficiency probably does not extend to heads greater than 150 feet, although for convenience the table has been extended to show higher figures.

From table 32 it is seen that 100 feet of 8-inch pipe will require from 7.5 to 10.2 feet of friction head for a velocity of 10 feet per second. Assuming a discharge pipe, level with the pump, it would be capable of pumping through a pipe from 30.19/10.2 x 100 = 296 to 30.19/7.5 x 100 = 402 feet long, depending upon the size and character of the gravel and sand particles.

If the discharge pipe does not need to be longer than 200 feet the friction head necessary would range from 15 to 20.4 feet, and there would be 30.19 - 20.4 = 9.79 to 30.19 - 15 = 15.19 feet to elevate the material. The pump could then pump material at 10 feet per second through 200 feet of 8-inch discharge pipe, the end of which could be 9.79 to 15.19 feet above the center line of the pump, depending on the size and character of the sand and gravel.

Since the sand and gravel composed 10 percent of the material pumped, table 33 shows that the pump would handle 209 cubic feet per minute, or 20.9 cubic feet of sand and gravel.

Converting this to hourly capacity it would be 20.9 x 60 = 125.40 cubic feet, or 46.5 cubic yards.

At 10 percent solids and a velocity of 12 feet per second the pump would deliver through 212 to 262 feet of level 8-inch pipe or through 200 feet of discharge elevated from 1.79 to 9.19 feet. The delivery would be 25.1 cubic feet of sand and gravel per minute, or 56 cubic yards per hour.

Thus it is evident that with a constant pump speed an increase of 2 feet per second in velocity has increased capacity but has cut the length of level discharge pipe an amount ranging from 84 to 140 feet, or with a constant length (200 feet) of discharge it has cut the elevation to a maximum of 1.79 to 9.19 feet.

In other words, to maintain the same length of level discharge pipe an increase from 10 to 12 feet per second in velocity and consequent capacity would require that the speed of the pump be raised to 587 r.p.m. At this speed the elevation of the end of the discharge pipe, if 200 feet long, could be increased to a maximum of 13.72 to 21.12 feet.

As is evident from the foregoing discussion, it is impossible to present a table of pump capacities unless it is confined to certain definite values for the different variables. However, it is believed that by the use of the tables given herein an operator can apply the values coincident with his local conditions and answer his problems.

A rough approximation of pump capacity, in which the ratio of solids in the discharge is assumed as 10 percent, the velocity of discharge as 12 feet per second, and the total head to be within reasonable limits, may be made as follows:

The capacity in cubic yards per hour equals seven eighths the square of the pump diameter in inches.

In the example cited (above) the 8-inch pump was calculated to have a capacity of 56 cubic yards per hour. If this rule is applied, 8 x 8 x 7/8 = 56 cubic yards.

Working Capacity

The previous calculations, while based upon experimental data, should nevertheless be classed as theoretical and will probably represent what may be termed "average conditions." They can easily be greatly exceeded in handling loose, fine sand and, on the other hand, may be greatly reduced in attempting to recover coarse or partly cemented gravel.

In any case the theoretical capacity should be reduced by 25 percent to obtain a safe working capacity.

CLAMSHELL DREDGE

The term "clamshell", as applied to a dredge, specifically refers to the use of a clamshell bucket swung from the boom of a crane mounted on a floating hull. The term, however, is commonly used to cover the same type of excavator using an orangepeel or even in some cases a dragline bucket. The general term for this type of excavator is the "grapple" dredge.

Fundamentally the clamshell dredge consists of a barge upon which is mounted an excavator crane. The crane may be the mobile land type temporarily placed on the barge for use as a dredge, or it may be dismounted from its chassis and permanently fixed on the barge. In other cases the crane element is built integrally into the hull construction. Either the clamshell, orangepeel, or dragline bucket may be used, regardless of the type of mounting.

The barge or scow on which the crane is mounted may serve as a base only, or the crane may be placed at one end and the balance used as cargo space for gravel loading or temporary storage. Some producers install machinery on the hull for either partial or complete treatment of the excavated sand and gravel. (See fig. 11.) This type of dredge as used for sand and gravel excavation is seldom self-propelled, although for river and harbor work the hull often carries driving engines as well as cargo space.

The clamshell dredge may then perform the single function of excavation; it may combine excavation with storage; it may combine excavation with partial or complete treatment; or it may combine excavation with transportation.

Clamshell dredges are essentially submarine excavators but may be used to excavate material to a limited extent above their floating base. As an example, the dredge may remove a thin overburden from a low bank and cast it to waste in the water. It can then remove the gravel from above and below water level and load it either into barges moored alongside or to cars running on tracks laid on the land surface beyond the stripped area.

Like its land counterpart, the clamshell dredge depends upon the weight of the bucket and the shape of its cutting edges to penetrate and dig gravel. It has no means of forcing the bucket into the deposit except to the limited extent possible when using a dragline bucket. The impact of the bucket on the deposit is less in submarine excavation, however, because of the buoyant effect of the water. Hence the dredge has more difficulty in penetrating compacted gravels than a crane operating in a dry pit. With this exception the dredge is subject to the same difficulties in excavating hardpan as the crane.

In excavating submerged deposits containing boulders, the operator must spot the bucket blindly because of his inability to see below the water surface. Hence more time is required than in similar dry excavation.

Mounted on an unstable floating base, the clamshell dredge may not have the lifting power of similar land equipment. The lifting power is limited by the buoyancy of the barge mounting. The action of the dredge may be compared to the mechanics of a simple lever in which the end of the boom is the point of power application, the center of gravity of the dredge the point of lift, and the base of the crane the fulcrum. As the lever arm or lift increases, the fulcrum is forced deeper into the water. When digging to either side this tends to careen the dredge. Hence the designer must resort to marine-engineering principles in addition to those required for designing land equipment in maintaining stability.

The dredge in which the boom and excavating equipment are integral with the hull is usually equipped with spuds. When dropped to the bottom and forced into the bed they act as legs and stablize the hull against careening.

When digging at excessive depths it is impossible to use spuds, and the stability of the dredge and its lifting power are entirely dependent on the buoyancy of the hull. When dredge hulls are properly designed to fit the operating machinery, the lifting power will equal that of similar land equipment.

When dragline buckets are used on this type of dredge additional strain is thrown upon the spuds by the drag of the bucket. This is usually met by supplementing the spuds with cables and anchors.

Clamshell dredges are probably in greater use as excavators for river channels or underwater foundations than for commercial sand and gravel production, although their use for the latter is not at all unusual.

The cycle of operations is similar to that of the excavator crane but is usually of longer duration. There are various reasons for this. Both hoisting and lowering speeds are reduced when the bucket is submerged in water. Swing acceleration is reduced for the same reason, although deceleration may be increased. Moreover, the time required to hoist and lower the bucket is usually longer with dredges because of their common use for deeper excavation. However, this does not always follow. In removing gravel from the same submerged depth, the operating cycle of the land crane may be greater than that of the dredge because the elevation of its working base is higher on the bank and because it must hoist its bucket

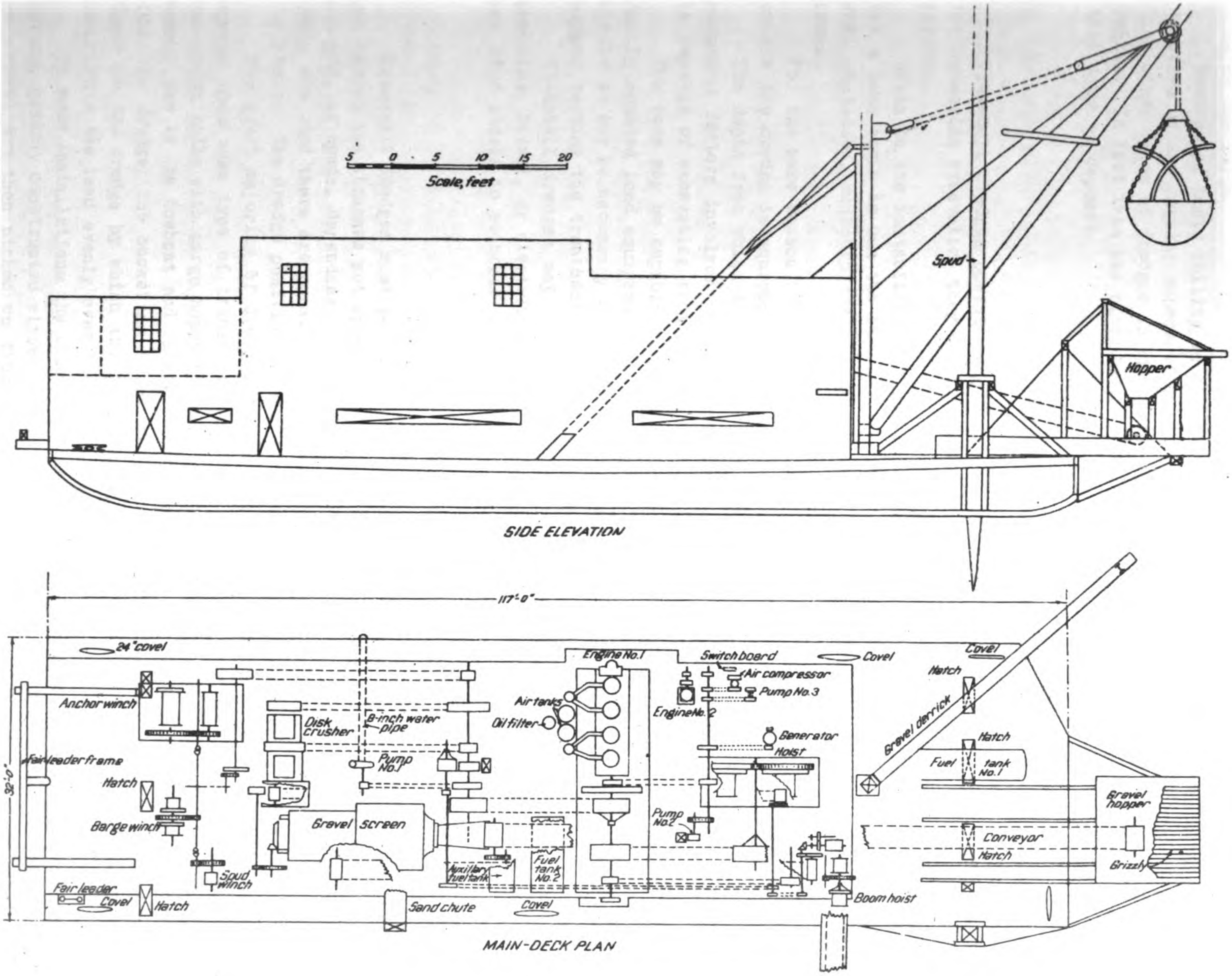

Figure 11.—Side elevation and main-deck plan of clamshell dredge.

to a car on the bank. The dredge, on the other hand, may need to hoist only to clear the side of the barge.

Because of their ability to take succeeding bucket loads from independent points irrespective of any regular scheme of excavation, clamshell dredges operate to better advantage than other types of dredges in river deposits containing quantities of sunken logs and other debris. In fact this has often been the deciding factor in determining the dredge to use on this type of deposit.

Structural Limitations

Clamshell dredges operate only from the surface of a body of water. Used principally for submarine excavation they can remove material from only a limited height above the water surface.

Owing to the instability of their floating base they cannot ordinarily operate with as low a boom angle as can the land crane. For this reason their operating reach may be somewhat curtailed, although their dumping height may equal that of a similarly equipped land crane.

For the same reason the tendency to overturn is greater with the dredge than the crane unless the dredge is equipped with spuds.

The depth from which a clamshell dredge can excavate, however, is limited only by the economic factors involved in the lengthened operating cycle. For this reason the clamshell is capable of excavating from greater depths than any other type of dredge.

The boom may be capable of complete revolution through 360°, as in the case of temporarily mounted land equipment, or the movement may be confined to only such portion of the circle as may be necessary to load barges moored alongside or to reach the hold or receiving hopper serving the treatment machinery on the dredge itself.

Clamshell dredges may be operated with any convenient type of power, either steam, gasoline, Diesel, or electric. Like the shovel and dragline, their intermittent action does not lend itself to economic consumption of electrical power.

Service Equipment Required

Clamshell dredges must be equipped with some sort of apparatus to hold them in position and resist the stresses set up while digging. These are supplied by winches with cables and anchors, or spuds, depending upon the conditions under which the dredge is operating. When spuds are used there are usually 3, 1 at each bow corner of the hull and 1 in the center at the stern. The dredge position is shifted by walking on the 2 forward spuds.

The great majority of dredges of this type are not self-propelled and must therefore depend upon some type of transportation unit. For river and harbor work, self-propelled, sea-going hulls with cargo hoppers are often used. The type of transportation unit in most common use is the towboat and barge. In ordinary practice the empty barge is moored alongside the dredge; the bucket is swung over the barge and dumped. Usually winches are provided on the dredge by which the barge can be moved forward and backward while loading to distribute the load evenly over the cargo space.

In some installations the clamshell dredge dumps its load to a hopper covered by a protecting grizzly constructed either on an auxiliary barge or on the dredge itself. The sand and gravel are then picked up from the hopper by a dredge pump and conveyed through pipe lines to the treatment plant. In other installations the conditions are reversed and the excavation is done by hydraulic dredge which pumps to submarine storage near the plant; from there the gravel is picked up by a clamshell dredge and elevated to a hopper or other equipment feeding the plant.

In installations in which the digging equipment is mounted on the end of the barge, the center and other end of which are fitted for cargo carrying, this type of construction has two functions. In one, the dredge is towed to the deposit, loads its cargo capacity, is returned to the plant or unloading site, and there uses its excavating equipment to unload itself. In the other, the dredge remains at the digging site and loads barges as they are brought to it. Between visits by the towboat, in case of unusual delay, it may continue to dig gravel and load its own hold. Upon arrival of a fleet of empties it can then unload its hold to them.

In more elaborate types of dredge which either partly or wholly treat the sand and gravel, provision must be made for installation of this equipment and the power to operate it. This involves careful hull design and distribution of the various units to maintain equilibrium under all operating conditions.

Capacity

The capacity of a clamshell dredge is subject to the same variable factors as that of similar land equipment, in addition to variables pertaining to marine operation, such as storms, floods, leakage of hulls, etc.

When it is used to excavate from excessive depths, its capacity is reduced by the lengthening of its time cycle due to that depth.

Rated or theoretical capacity for a single unit size cannot be computed because there is no common base from which to start calculations. Whereas the shovel or dragline has a fairly limited uniform starting and stopping point for each digging cycle, the clamshell dredge is constantly changing its hoisting, lowering, and swinging range as material is dug.

Working capacity may be calculated approximately for operating conditions, at each particular site, but this requires data which vary with each location. Generally it may be said that the working capacity of a clamshell dredge will compare favorably with that of a crane or dragline operating under similar conditions as to depth of digging and character of material being handled.

With the clamshell dredge as with other types of equipment, the skill and efficiency of the operator is a large factor in capacity. This is probably of even greater moment with the dredge than with the crane. The operator must constantly keep in mind the danger of overturning the dredge. He must spot each bucket blindly, since he cannot see below the water surface. If the deposit is fouled with sunken logs and other debris, he must be expert in being able to dig around and remove them, or, if too large to remove, in obtaining a maximum of material from their vicinity.

The time required to spot a bucket for dumping will be reduced in the operation of a clamshell dredge because of the larger transportation unit. On the other hand, care must be exercised to load barges equally over their whole area. Otherwise they may become dangerously unbalanced on one side or end.

LADDER DREDGE

The ladder dredge was originally developed as a tool to excavate placer gold deposits. These deposits seldom contain more than a dollar and often as low as 10¢ in gold per cubic yard of gravel, hence the volumetric ratio of gold to gravel is very small. The cost of transporting the excavated material to a shore treatment plant, where the gold could be extracted, and then disposing of the great volume of gravel, which had no commercial value to the placer miner, was too great for economic operation. This type of dredge, therefore, was from necessity developed to dig, treat, and dispose immediately of huge quantities of material with as little handling and in as short a time as possible. To reduce labor costs the design embodied complete mechanization. In addition, since placer deposits are often extensive, although comparatively shallow and narrow, the unit must have operating mobility although it does not require the ability to propel itself over long distances. Ladder dredges for placer mining evolved into huge, powerful, self-contained machines requiring a large initial investment but capable of low operating costs.

Since the recovery of commercial sand and gravel combines the necessity of handling large tonnages at low cost and the immediate disposal of waste, this type of dredge admirably solved the problem for the gravel producer where local conditions permitted its use. The ladder dredge has therefore become an important tool in gravel production.

The design of hull and digging equipment has followed closely that for gold dredges. The machinery for treating the gravel has been altered to fit the needs of the gravel producer. The original idea of a big, powerful unit has remained, and this type of gravel dredge while built in various sizes and capacities, still remains a tool for large rather than small production.

Ability to dig and treat large quantities at the excavation site so that only marketable material needs to be transported enables the ladder dredge to operate at maximum distances from distributing points.

Ladder dredges do not have storage space aboard, except as it may be needed to provide even flow between the units of the treatment equipment.

In the absence of self-propelling machinery, except such as is needed to shift position as excavation progresses, they do not perform the function of transportation. Neither is this type of dredge designed for excavation only.

In combining excavation and treatment functions these dredges may be designed for either partial or complete treatment. In either case the excess fine sand and silt are eliminated. When designed for only partial treatment the dredge separates the sand from the gravel and two products only are made. Otherwise both sand and gravel are further washed, crushed, and sized for shipment as finished products.

Neither the design nor the construction of ladder dredges is standardized. Certain component units follow standards developed by experience, but the complete assembly differs with each dredge. Because of this individualistic design they must be assembled at the site at which they are to be used, or at a shipyard from which they can be floated to their destination.

Although frequently used in ponds of their own making in placer mining, ladder dredges are less frequently so used in gravel production probably due to the high initial cost and the scarcity of sufficient workable area in close proximity to large markets. Because of their size and unsuitability to withstand storms and heavy seas, their use has been confined largely to river deposits or well-sheltered lake or ocean beaches.

Ladder dredges are best adapted to removing horizontal slices from submerged deposits.

Dredge hulls may be of timber or steel construction. They are rectangular in shape with vertical sides and vertical or overhanging bow and stern. At the bow the hull is cut by a central well extending a considerable distance amidships. In plan the hull is a rectangle with the bow split to form the arms of a two-pronged fork.

The operating principle, insofar as it concerns excavation, is that of an enlarged and powerful bucket elevator. The digging element consists of the elevator supported by and revolving around a structural-steel "ladder" or boom. One end of the ladder is hinged on the dredge hull in such a position that the other end is free to be lowered or raised through the well in the bow. When in operation the free end of the ladder and elevator is lowered to contact the gravel in the stream bed. It may be raised clear of the water for inspection or repairs or for change of dredge location.

The structural-steel ladder may be a single rigid unit hinged at its upper end or it may be built in two parts, the upper portion integral with the superstructure and the lower portion hinged at the deck line. The lower end in either case is supported by a cable reeved through a series of multiple blocks hung from a bow gantry usually built in the form of an A-frame straddling the central well in the bow. By means of a hoist operating the cable and blocks the ladder may be raised or lowered at will.

At either end of the ladder is a pulley or spool around which the bucket assembly revolves. The spool at the upper end of the ladder, called the "upper tumbler", is designed as a sprocket to act as the drive for the bucket line. That at the lower end, called the "bottom spool", acts merely as a guide for the bucket line but must be of unusually heavy construction to withstand the abrasion to which it is subjected. While digging, the lower end of the ladder rests on the stream bed, the whole assembly inclined at an angle varying with the depth of the digging and the ladder length. The maximum angle of inclination is 45° below the horizontal and the buckets travel upward on top of the ladder and downward on the under side.

The design of the bucket line varies in detail with different manufacturers. There are two general types — the slack line and the tight line. In the former (fig. 12) the total length of the bucket line is appreciably greater than double the ladder length. This permits the bucket line to hang in a slack loop on the under side of the ladder. In consequence, several buckets simultaneously contact the deposit in a more or less horizontal line. Advocates of this design claim that in deposits containing boulders the flexible bucket line allows more digging time for each bucket resulting in a higher percentage of capacity load for individual buckets.

In this type of construction the buckets are fastened to two chains, the links of which engage in sprockets on the upper tumbler. The buckets may be spaced on the chain at any desired pitch or may be continuous, each pinned to the next and forming a link in the chain.

In the tight line design (fig. 13) the buckets are continuous. The bucket line exceeds twice the ladder length only enough to provide flexibility. In this arrangement the digging is done as each bucket rounds the bottom spool.

Each type of design has its advocates and critics.

On some dredges the upper end of the ladder is hinged close to the bow so that the lower end is at all times in advance of the hull. In others the ladder is swung some distance back of the bow. In shallow digging the point of excavation may then be in advance of the hull, but as depth increases and the ladder is lowered this point retreats to a position vertically below the hull. The greater forward extension allows more room on the hull for treatment machinery and permits undercutting and caving a bank at a safer distance from the dredge.

The ladder dredge excavates by forcing the buckets into the deposit, cutting successive slices as each revolves around the lower spool. In loose sand the ladder is suspended on the hoist cable, and the buckets pick up the gravel as it caves to them. In stiff clay or cemented gravel direct force may be applied to the cutting edges of the buckets by lowering the ladder and allowing its weight to bear. Because of the weight, power, and saw-tooth cutting action of the bucket line surprisingly tough or compacted material can be excavated.

The ladder dredge is at a disadvantage in deposits containing appreciable amounts of boulders larger than can be carried in the buckets, or wherever the deposit is contaminated with sunken logs. With an excess of large boulders these collect in the pit formed by the digging buckets as they are freed from the finer material. When a sufficient number accumulate they cause trouble by preventing the buckets reaching virgin material or by stopping the bucket line. The ladder must then be raised and the dredge swung to a new position. Where large sunken logs are present the buckets catch under them and stop the line. This type of dredge has no means of picking up boulders or logs and moving them to one side as has the clamshell and dipper dredge.

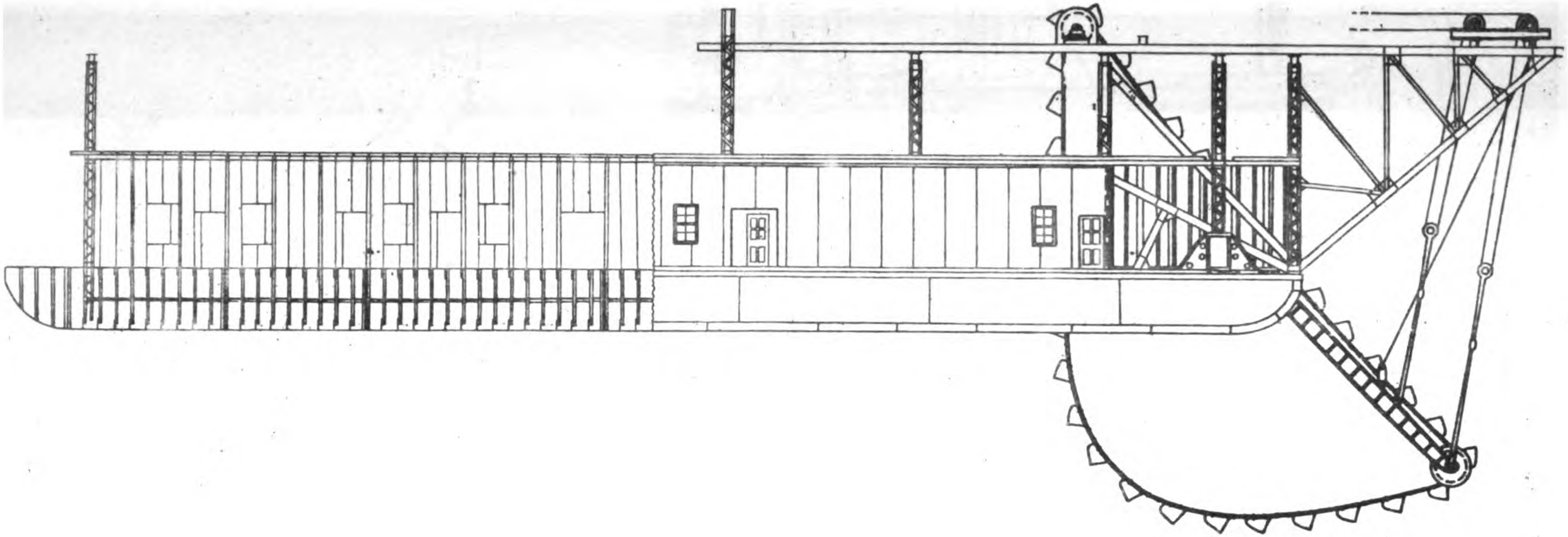

Figure 12.—Side elevation of dredge showing slack bucket line.

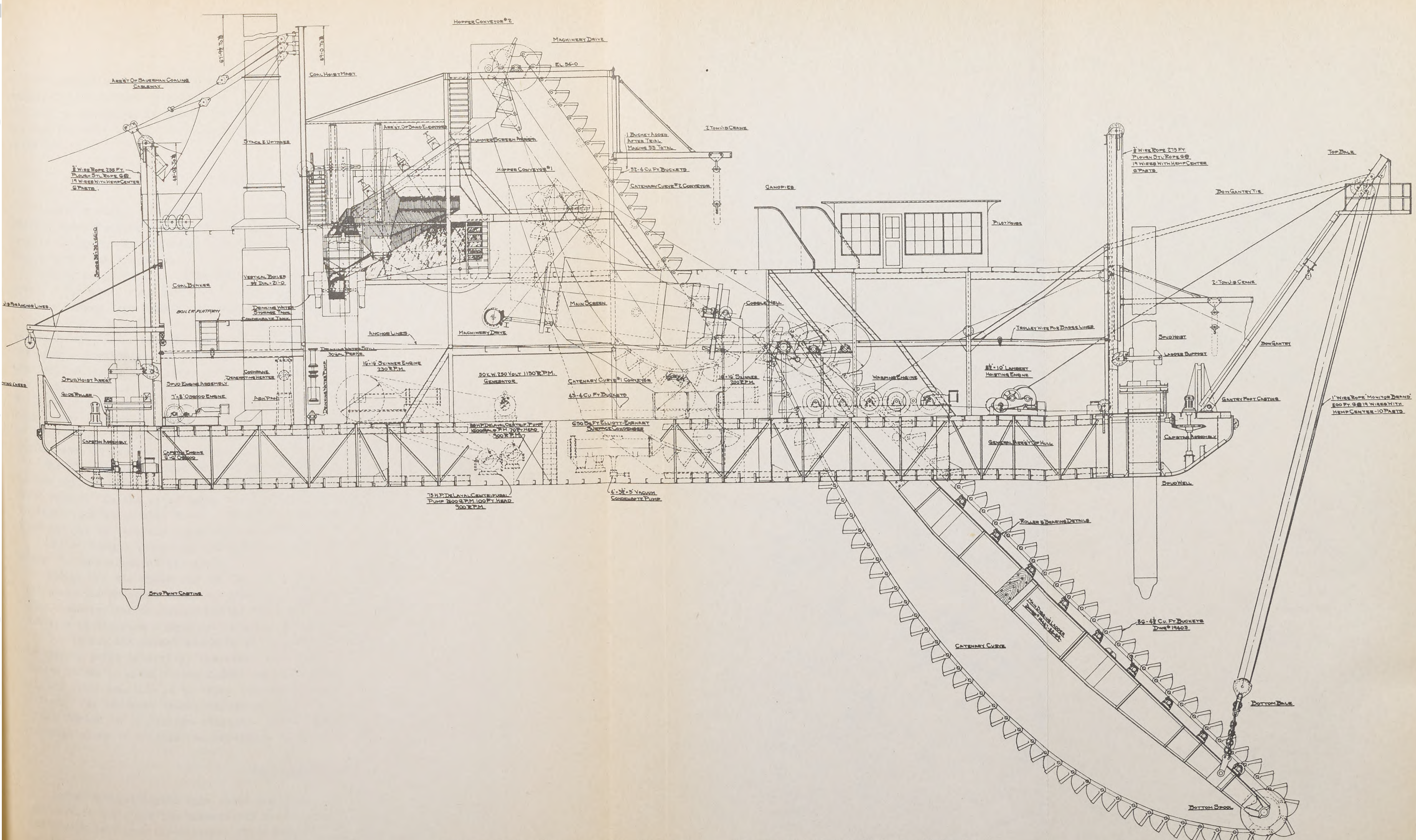
Hopper Conveyor #2
Machinery Drive
El. 54-0
Arr'gt. of Sauerman Coaling Cableway
Coal Hoist Mast
67'-9½ To ℄
59-0 To ℄
45-0 To ℄
Stack & Uptakes
Arr'gt. of Sand Elevators
Hummer Screen Arr'gt.
1 Bucket Added After Trial Making 53 Total
2 Ton Jib Crane
⅞" Wire Rope 235 Ft. Plough Stl. Rope 6@ 19 Wires With Hemp Center 6 Parts
Hopper Conveyor #1
52-4 Cu. Ft. Buckets
Catenary Curve #2 Conveyor
Canopies
Pilot House
⅞" Wire Rope 275 Ft. Plough Stl. Rope 6@ 19 Wires With Hemp Center 6 Parts
Top Bale
Bow Gantry Tie
Coal Bunker
Vertical Boiler 5½' Dia. - 21-0
Boiler Platform
Drinking Water Storage Tank
Condensate Tank
Jib For Anchor Lines
Anchor Lines
Machinery Drive
Main Screen
Cobble Well
2-Ton Jib Crane
Trolley Wire For Barge Lines
Spud Hoist
Ladder Support
Bow Gantry
Drinking Water Still 30 Gal. Per Hr.
Drinking Water Pump
16-16 Skinner Engine 230 R.P.M.
Cochrane Deaerating Heater
Spud Hoist Arr'gt.
Spud Engine Assembly
Guide Roller
7 x 8 Osgood Engine
Ash Pan
50 K.W. 250 Volt 1150 R.P.M. Generator
Catenary Curve #1 Conveyor
43-4 Cu. Ft. Buckets
16 x 16 Skinner 300 R.P.M.
Warping Engine
8½ x 10 Lambert Hoisting Engine
Gantry Foot Casting
1" Wire Rope "Monitor Brand" 800 Ft. 6@ 19 Wires With Hemp Center - 10 Parts
Capstan Assembly
Capstan Engine 6-6 Osgood
85 H.P. DeLaval Centrif. Pump 1600 Gal. P.M. 70 Ft. Head 900 R.P.M.
650 Sq. Ft. Elliott-Ehrhart Surface Condenser
General Arr'gt. of Hull
Capstan Assembly
Spud Well
75 H.P. DeLaval Centrifugal Pump 2600 G.P.M. 100 Ft. Head 900 R.P.M.
4 x 5½ x 5 Vacuum Condensate Pump
Roller & Bearing Details
Spud Point Casting
Main Digging Ladder Dwg. # 19467-88-89
86-4½ Cu. Ft. Buckets Dwg. # 19403
Catenary Curve
Bottom Bale
Bottom Spool
38'-6" Below W.L.

Figure 13.— Elevation of ladder dredge with continuous buckets on tight line.

To provide against damage when boulders or logs are encountered, suitable disengaging equipment is sometimes provided, so that when a pull beyond the safe limit is encountered the driving mechanism is thrown out of gear and the bucket line stops. Skillful operators can usually work around such situations by raising and lowering the ladder while it is in operation.

Structural Limitations

Ladder dredges, because of their heavy and powerful digging units and complement of washing and screening machinery, require large hulls of greater draft than clamshell or hydraulic dredges. Consequently they cannot be moved from place to place as easily and require deeper water for operation.

Having no propelling machinery, they cannot move over extended distances by their own power. The usual complement of winches and cables enables movement while digging, but in order to change from deposit to deposit they must rely upon towboats or tugs.

The depth to which a dredge can dig depends entirely upon its individual design. Depth ranges do not follow either size of bucket or length of spud. Any ladder dredge can dig from the minimum depth at which the hull can be maneuvered to the maximum permitted by the length and inclination of its ladder. The length of the ladder on any dredge is designed to suit the conditions under which that particular unit may be operated. Thus a machine wielding a 2 1/2-cubic foot bucket line may be designed with a short ladder for shallow excavation or a long ladder for deep digging. Similarly, the 16- or 21-cubic foot dredge may have a short or long ladder. Either size may also be built for low or high bucket speeds. Excavation depths reach 90 feet and are commonly 30 to 50 feet below water line.

Where a dredge is required to undercut and cave a bank, the location of the ladder hinge on the hull is important. A short ladder hinged on the bow may excavate a comparatively high bank safely. On the other hand, a longer ladder hinged farther amidships may have an equal forward reach at greater depth. In either case, safety in bank caving requires a hydraulic pump and jet to cave the upper part of the bank.

Ladder dredges discharge the products made by gravity flumes, conveyor belts, or other means, to barges moored alongside.

Ordinarily the upper end of the ladder is carried high on the hull superstructure so that excavated material feeds by gravity to the washing and screening equipment. In some cases, however, the discharge end of the ladder is kept low for hull stability, and lighter auxillary elevators are employed to carry the material to the height desired. (See fig. 13.)

The ladder and bucket assembly is capable of vertical motion only. In order to change the digging point laterally, therefore, the whole dredge must be swung. Because of the excessive stress to which a long ladder would be subject if the dredge was moved while excavating, the usual practice is to raise the ladder clear of the deposit while the dredge is being shifted. For the same reason ladder dredges are held in position by spuds rather than anchors attached to cables and winches. There is too much flexibility in the latter type of anchorage alone to provide the necessary stability for the thrust of the bucket line.

Service Equipment

Ladder dredges depend upon other equipment for transportation. The most common form of such service units are the towboat and barge. Having no storage space aboard, the dredge is wholly dependent upon the transportation unit for capacity production. If the length of haul and transportation units are so coordinated as to have empty barges at the dredge at all times the latter can usually deliver its designed capacity.

By the use of winches mounted on the dredge hull in suitable locations, the dredge can be shifted from one digging position to another through cables and anchors. Ladder dredges are held in digging position by means of spuds supplemented by anchors and cables. Spuds may be located at the bow or stern as conditions require but are limited to 1 or 2 at the stern for small dredges, while those of large capacity may have 4 - one at each corner.

Other winches are provided for shifting barges while they are being loaded.

Ladder dredges are essentially self-contained digging and treatment plants. As such, they operate at a distance from any source of power. For this reason they usually carry their own power plant aboard. Power may be either steam, gas, oil, or Diesel engine, or any of these may be used as the prime mover to generate electric power. Electric power from a source on shore may be used where the dredge is not required to move long distances. As this seldom occurs in sand and gravel excavation such dredges generate their own power. The size of the power unit supplied to any dredge is a matter of individual requirements and cannot be tabulated by dredge size or capacity.

The usual skiffs or motor tenders are necessary to transport men and supplies to and from shore and to place and move anchors.

Ladder dredges are equipped with washing and screening equipment, but since this paper deals with excavation a discussion of such units will be taken up in a following publication.

Capacity

The capacity of a ladder dredge depends upon the size of the buckets, their spacing on the line, the speed at which they travel, and the ability of the operator to keep them coming up with a maximum load without stalling. The size and spacing are fixed for each installation, and usually the speed is also fixed for each particular dredge. However, these are not standard with different dredges, hence two units with the same size buckets may be capable of totally different capacities due to variations in speed or spacing. Moreover, the skill of the operator in handling a specific unit may influence the capacity by 100 percent or more. For these reasons exact calculations as to capacity cannot be made except for individual dredges for which all the necessary elements are known. If bucket size, spacing, and speed are known the theoretical capacity is easily computed, but the average working capacity is seldom more than 50 to 60 percent of theoretical. In ideal conditions, however, these ratios may be exceeded.

Buckets as furnished by builders range from 2 1/2 to 21 cubic feet in size. Speeds range from 60 to 90 feet per minute corresponding to the dumping of 15 to 40 buckets per minute. Spacing or pitch in lines of the continuous-bucket design depends on the size and design of individual buckets, although the variation in pitch does not increase directly with bucket capacity. In noncontinuous bucket lines the pitch is a matter of the individual preference of the designer or operator.

As an example of capacity calculations assume a dredge is fitted with 2 1/2-cubic foot buckets spaced 2 feet apart and traveling at a speed of 60 feet per minute. Such a dredge theoretically should deliver 2 1/2 cubic feet of material each 2 seconds, or 167 cubic yards per hour. However, it is seldom, and then only for short periods, that each and every bucket comes up completely filled, even in the most favorable digging conditions. Moreover, dredges seldom operate over 80 percent of the possible working time. Hence, calculations for working capacities should be based on 50 to 60 percent of theoretically calculated figures.

As an indicator of working capacities of various sized dredges, table 39 has been compiled from reports of operations from various sources. The capacities listed are for actual excavation under what may be termed "average working conditions."

TABLE 39.- Working capacities of ladder dredges[1]

Bucket capacity, cubic feet	Dredge capacity, tons per hour From-	To-
1.5	38	75
2.5	63	160
3.0	112	200
3.5	45	135
4.0	188	260
5.0	260	320
5.5	282	
6.0	188	360
7.0	263	358
7.5	216	475
8.0	450	563
8.5	450	
9.0	450	968
9.5	412	
10.0	512	900
13.5	640	800
15.0	750	950
17.0	860	
18.0	900	1,200
21.0[2]	450	600

[1] Figures compiled from operating records of gold dredges, 1923-33.

[2] Pitch of buckets, 5 feet.

Hennen Jennings[3] gives several tabulations of the performance of gold dredges in Montana from which table 40 is abstracted.

From this calculation it is apparent that the actual tonnage dug by each dredge was considerably less than the theoretical tonnage even when corrected to the actual average speed of the bucket line. This discrepancy must then be due to partly filled buckets. Calculating the actual tonnage produced against the theoretical at the average speed, dredge, no. 1 worked at 66.4 percent capacity, no. 2 at 61.2 percent, no. 3 at 53.8 percent, and no. 4 at 64.0 percent capacity. In other words, a reduction of 40 to 50 percent below theoretical capacity is indicated in these examples due to partly filled buckets. If actual tonnage was calculated against theoretical tonnage at the designed speed the reduction would be still greater. However, it must be borne in mind that these dredges were digging placer gold, and in so doing greater care was used to clean the bedrock thoroughly than would be exercised in digging gravel for commercial purposes. This cleaning of bedrock probably accounts for the low efficiency in filling buckets.

Since this careful clean-up is unnecessary in gravel excavation, it is estimated that working capacity can be calculated fairly accurately as 60 percent of the theoretical computed from speeds and bucket sizes.

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[3] Jennings, Hennen, History and Development of Gold Dredging in Montana: Bull. 121, Bureau of Mines, 1918, pp. 63.

TABLE 40.- Performance data of four electric gold dredges in Montana

Item	Dredge no.			
	1	2	3	4
Date built	1908	1908	1906	1911
Ladder length.....feet	69	80	100	116
Digging reach below water.....do.	30	35	45	55
Average depth dug.....do.	22.1	28.1	40.8	45.3
Type of bucket-line drive	Belt	Belt	Gear	Gear
Power on bucket line.....hp.	100	100	150	550
Number of buckets	60	80	80	80
Bucket pitch.....inches	32.75	32.75	32.75	40.0
Bucket capacity.....cubic feet	7½	7½	9½	16
Buckets per minute, theoretical	16	15	15	20
Buckets per minute, average operating	15.75	12.98	14.15	18.62
Operating time (percent of total)	71	67	65	65
Cubic yards dug per hour	174	132	161	420
Cubic yards dug per bucket	.18	.18	.19	.38
Total operating cost, cents per cubic yard	5.66	6.94	6.75	4.85

Author's calculations from the above data

Bucket speed, theoretical.....feet per minute	43.7	41.0	41.0	66.6
Bucket speed, average operating.....do.	43.0	35.4	38.6	62.0
Cubic yards per hour (full buckets):				
At theoretical speed	266	250	317	710
At operating speed	262	216	299	656

DIPPER DREDGE

The dipper dredge was developed as an excavation tool for ship-channel and other submarine excavation. It has been employed to only a limited extent in sand and gravel excavation. Although other types of dredges are capable of greater capacities, the dipper dredge has distinct advantages in recovering material from certain types of deposits.

In its essential features the dipper dredge is a power shovel mounted on a floating hull. (See fig. 14.) While the shovel is limited to dry and the dipper dredge to wet excavation, both wield a dipper on the end of a dipper stick mounted on a swinging boom. Aside from this similarity, the two units have little in common, either in structure or operation.

Like the shovel, the dipper dredge performs the single function of excavation. It neither transports nor treats excavated material.

The shovel is self-propelled and excavates material lying above its operating base. The dredge, on the other hand, is not self-propelled and excavates principally from below the surface of the water on which it floats. However, just as a shovel can dig a short distance below its base, so the dredge can remove banks extending a short distance above water line.

Structurally the dipper dredge consists of a rectangular, steel or wooden hull with vertical sides and vertical or overhanging bow and stern. At the bow a reenforced wood or structural-steel boom is mounted on a base capable of swinging horizontally through an arc of 180°, more or less. The boom angle may be fixed between 35° to 45° above the horizontal, or it may be adjustable by the proper arrangement of cable and blocks. The boom supports the

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dipper stick and dipper. On dipper dredges, however, both boom and dipper stick are longer and of heavier construction than on a shovel wielding the same size bucket.

The dipper dredge is a heavy, powerful machine capable of tearing loose heavy clay, cemented gravel, and even solid but comparatively soft rock such as shale which could not be removed by other types of dredges. It is also efficient in deposits containing a large percentage of boulders or those contaminated by sunken logs, tree trunks, or similar debris. An experienced operator can remove boulders too large to pass through the dipper, or he can pick up sunken logs and either cast them to one side or load them on floating barges.

While the dipper dredge is peculiarly fitted to recover material from deposits offering too many difficulties for other types of dredges, it must not be assumed that the dipper dredge cannot compete also in easy digging.

Like its land counterpart, this type of dredge can be converted to a floating dragline or clamshell dredge by changing buckets, boom, and possibly boom angle.

Usually dipper dredges are so constructed that they are capable of weathering fairly heavy seas and may be classed as more seaworthy than ladder dredges, although this depends upon the individual design.

Like other types of dredges, they must be built at the excavation site or at some shipyard from which they can be floated to their destination. Dipper dredges are more amenable to standardization in construction, or perhaps it would be more accurate to say that the component parts of a dipper dredge, and the whole assembly within certain limits, are susceptible to standardization. Just as the size of the bucket or dipper and the length of boom or dipper stick can be varied within the overturning limits of the chassis of the dragline, crane, or shovel, so can the same changes be made on a dipper dredge within the buoyancy range of its hull.

Structural Limitations

The depth to which a dipper dredge can dig, the height to which it can raise its loaded dipper, and the radius to which it can reach depend entirely upon the lengths of its boom and dipper stick. Variation in specifications based on the type of excavation for which they are constructed classify dipper dredges into two groups - deep-water dredges and ditching dredges. This differentiation parallels the two main classes of power shovels - the excavator and the stripping shovel. Ditching dredges, as their name implies, are used principally for excavating drainage ditches, and in such work they cast the excavated material to the bank on either side of the ditch. Barges rarely are used for conveyance in this work. This necessitates a higher and wider dumping range than is required for deep-water dredges which dump their material to barges. Because of this differentiation, ditching dredges like stripping shovels are fitted with longer booms and dipper sticks than deep-water dredges.

Ordinarily, the sand and gravel producer is not interested in the extra radial reach or dumping height of either ditching dredge or stripping shovel. However, peculiar local conditions may require them on a particular deposit; therefore, to present the selective possibilities available, the same procedure has been followed in tabulating the structural limitations of dipper dredges as was used with power shovels, that is, no differentiation is made between the two general types. Structural dimensions given in table 41 have been compiled from manufacturers' catalogs; in general, maximum lengths of boom, dipper stick, height of dump, and lateral reach represent the ditching type of dredge and the minimum figures represent the deep-water type, with a considerable overlap between the two extremes. On the other hand, maximum digging depth represents deep-water dredges.

The digging depth is of importance to the gravel producer in that if he contemplates the use of a dipper dredge he must provide the proper length of boom and dipper stick to enable the dredge to reach the bottom of his deposit or leave valuable material behind him.

The dumping height is of less importance because he has only to clear the height of the barge when empty. This, of course, varies with the type of barge used. The flush-deck barge usually rides higher when empty than does the hopper type, although this does not necessarily follow. In any case, dumping height required above the surface of the water is usually less than where a dredge is used for ditching and the dug material must be dumped to either bank.

The dumping radius is also of less importance because in ordinary practice the receiving barge is moored alongside the dredge and the radius available with the shorter boom and stick is sufficient to reach the center line of the barge. Dumping or rather digging radius is important when the dredge is excavating material extending a considerable distance above the surface of the water. With a long radius the dredge can be kept farther from the bank and thus be safer in case the bank caves.

The size, shape, draft, and construction of the dredge hull have a direct bearing on the operating range of the dipper dredge. The arrangement and distribution of operating machinery also affect dredge operation. Hulls must be designed and machinery so distributed as to provide the proper buoyancy and as nearly even keel as possible at all times. Hull construction must be such as to provide adequate strength to resist the terrific stresses set up by the digging dipper and the swinging of loaded dipper, stick, and boom from side to side.

Service Equipment

Dipper dredges are not self-propelled and therefore must depend upon towboats or tugs for movement from one location to another. Like other types of dredges, however, they can be advanced while digging by means of winches through cables and anchors. They can also be swung or "walked" along on their spuds.

To hold the dredge stationary and to prevent careening from the thrust of the dipper, this type of dredge is usually constructed with 2 forward and 1 stern vertical spud. Ditching dredges usually have the forward spuds hinged at the top so the bases can be swung outward and set on the bank at either side. In some dredges anchors and cables only may be used, but such an arrangement without spuds is not customary.

The machinery for generating power to drive the excavating engines, power winches, and usual complement of auxiliary machines is mounted on the dredge hull. Usually quarters for the operating crew are also a part of the structure.

Dipper dredges are usually powered by steam boilers and engines. Smaller sizes may be driven through clutches by gasoline or Diesel engines, and the larger units may use the Diesel engine as the prime mover to drive electric motors.

Because of the diversity of design, there is no exact relation between the horsepower of the power plant and the size of the dipper. Fifty horsepower per cubic yard of dipper capacity may be taken as an approximate indicator of the steam power required. Other types of power will usually exceed these figures in rating, but the plant installed should be designed to fit the needs of the dredge and local conditions.

Capacity

All factors that affect the capacity of a power shovel are present to increase or reduce dipper-dredge capacity. In addition, there are others peculiar to submarine excavation which tend to facilitate or reduce the rate of digging.

The dumping height of a dipper dredge used in the production of sand and gravel usually needs be sufficient only to clear the side of an empty cargo barge. Since these are built as low as possible, the dumping height necessary above water level is usually less than that required of a shovel above its operating base. This reduces hoisting and therefore cycle time. On the other hand, the dredge reaches much greater depths below water line than does the shovel, which increases its hoisting and cycle time. In addition, the up or down movement of the dipper under water is slower than in air because of the higher resistance of the denser medium. The swing motion (empty return) is slowed up for the same reason, although to a less extent, since the boom is seldom started to swing (loaded) until the dipper is clear of the water. The longer dipper stick and boom also tend to increase cycle time. To overcome this, more power is applied, but this requires heavier construction, reducing the rate of acceleration and deceleration.

Due to the buoyant effect of water, less effort is required to move submerged material than the same material in air. A boulder of exactly 1 cubic foot and weighing 150 pounds in air will require a force of 150 foot-pounds to raise it 1 foot in air. The same boulder submerged in water will weigh 150 - 62.5, or 87.5 pounds, and hence will require only 87.5 foot-pounds of force to raise it 1 foot if water resistance is neglected. This buoyancy is of advantage to the dredge. With a dredge and shovel of equal power excavating identical material, the effect is as if the dredge were digging a lighter material.

The character of the material dug will affect capacity as it does with the shovel. Sticky clay will cause suction as it is torn loose by the dipper. Cemented gravel will be just as hard to dislodge under water as in air. Loose boulders, however, because of their apparently lighter weight, will be easier to move. Sunken logs and tree trunks, for the same reason, can be handled more easily. As an example, a dredge can lift and set aside under water a water-logged tree trunk of greater weight than it could lift out of the water. In this way, such a log could be raised to the surface where lines could be fastened to it, and it could then be towed away by the tug.

The experience and ability of the dredge operator has an even greater effect on capacity than that of the shovel operator. The dredge runner must set his dipper into the deposit blindly as he cannot see the bottom. For the same reason he must clean the bottom by feeling rather than sight. Skill and experience are especially essential in hard digging where the cause of stresses cannot be seen.

The theoretical capacity of a dipper dredge will depend upon the size of the bucket, the digging depth below surface, the speed of hoisting and swinging, the arc of swing, and the height of lift above water line. Since any or all of these items may vary with each dredge unit, theoretical capacities cannot be computed without knowledge of all local conditions.

The working capacities of dipper dredges will necessarily be less than the theoretical ones because of the action of delay factors already discussed.

Table 41 has been compiled from a number of sources as a guide to approximate working capacities. In computing capacities, consideration has been given to the fact that the capacity of a given dredge will vary with the lengths of boom and dipper stick, as well as changes in the depth from which it is digging. The columns showing theoretical capacity are calculated from rope and revolving speeds and assume that a full bucket is handled each cycle. The spread between minimum and maximum is accounted for by the range in lengths of boom and dipper stick and the corresponding digging depths and dumping heights.

Working capacities as estimated make allowance for the customary delays to operation and for partly filled buckets. To arrive at these figures, the lower of the theoretical capacities has been reduced 50 percent and a cubic yard assumed as weighing 2,900 pounds, thus giving an estimated minimum working capacity. The maximum working capacity is computed by reducing the larger of the theoretical figures 50 percent and assuming that a cubic yard weighs 3,240 pounds.

These figures are estimates only, and it is easily conceivable that under the most favorable conditions the maximum capacities may be greatly increased. They may even be doubled for short periods. However, it is felt that the figures given will represent the probable working range day in and day out, including delays of all kinds.

TABLE 41.- Dipper-dredge working ranges and estimated capacities

Dipper capacity cubic yards	Boom length, feet		Dipper stick length, feet		Digging depth below surface, feet		Dumping height above surface, feet		Dumping radius, feet		Capacity per hour			
											Maximum theoretical, cubic yards		Working, tons	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1/2	20	30	16	22	8	12	4	10	15	30	30	70	22	57
3/4	25	35	19	25	10	14	6	12	20	35	35	90	25	73
1	35	60	25	40	13	20.5	9	27	30	60	40	110	29	89
1 1/4	40	60	28	40	14.5	20.5	12	27	35	60	45	140	33	113
1 1/2	40	65	28	43	14	25	11	29	35	65	50	150	36	122
1 3/4	40	75	28	49	14	24.5	11	35	35	75	45	175	33	142
2	40	90	28	58	13	28	10	42	35	90	50	200	36	162
2 1/2	40	90	28	58	13	28	10	42	35	90	65	240	47	194
3	50	100	40	64	20	32	12	48	55	100	90	280	65	227
3 1/2	60	100	40	64	20	32.5	21	48	55	100	120	340	87	275
4	55	85	....	60	28.5	37	25	39	75	94	150	250	109	200
5	55	95	62	65	31.5	40	14	43.5	50	104	120	300	87	243
10	60	....	64	....	....	40	14	18	52	68	360	450	261	365

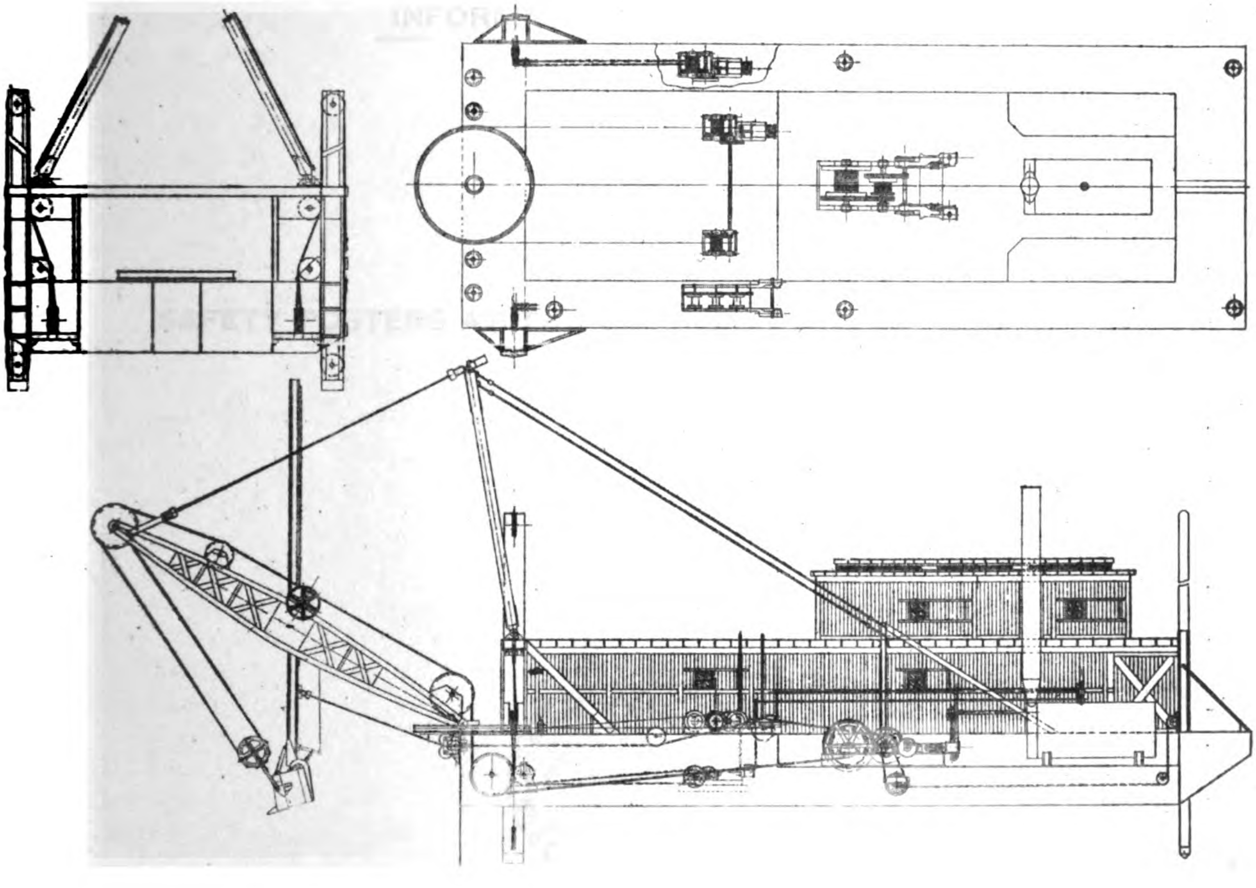

Figure 14.— Front and side elevations and plan of dipper dredge.